

Today

- Quantum mechanics
(in one easy lesson)
- Info about final

Features of QM: I

A series of experiments in the early 20th century showed that

- Small particles act like waves.
- Waves act like small particles.

Features of QM: II

We have an equation for the waves:

$$-\frac{\hbar^2}{2M} \frac{\partial^2 \psi}{\partial x^2} = i\hbar \frac{\partial \psi}{\partial t}$$

Features of QM: III

The Heisenberg Uncertainty Principle limits the information we can have about a particle's position and momentum:

$$\Delta x \Delta p \gtrsim \hbar$$

Features of QM: IV

We can do a two slit diffraction experiment with electrons instead of light waves.

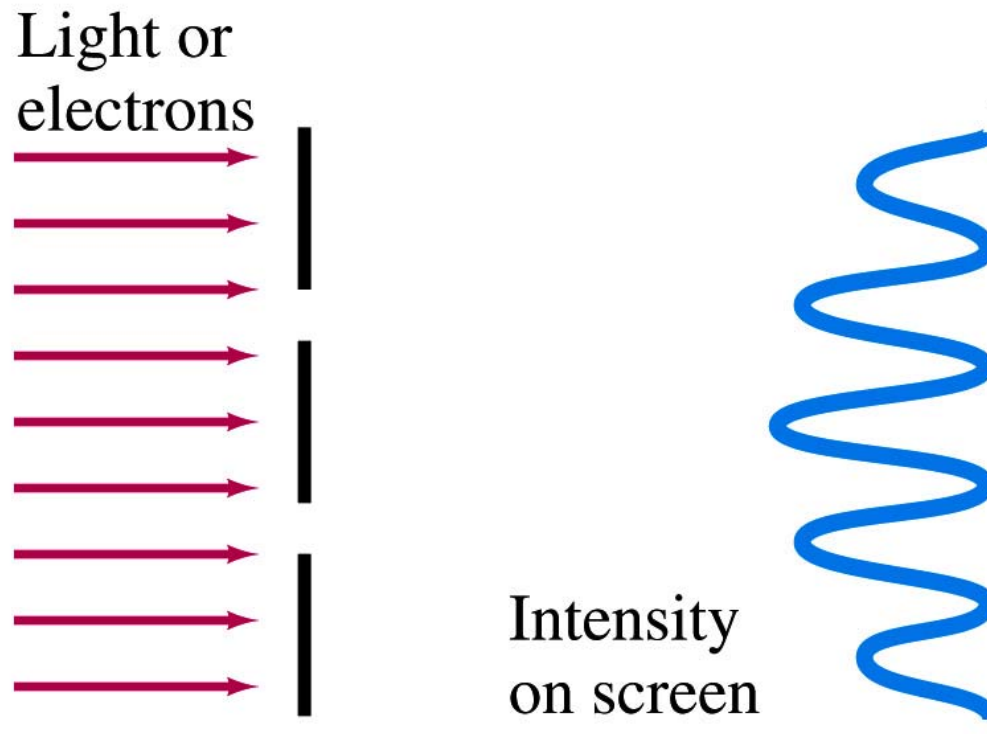


Fig. 39-3

Features of QM: V

The wave-like interference pattern builds up one particle at a time.

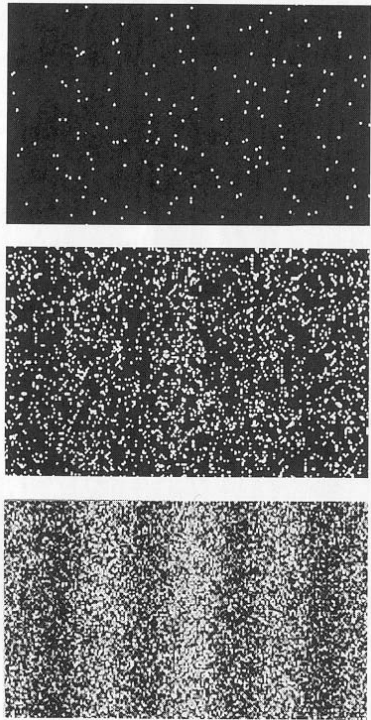


Fig. 39-4

Final Exam

- Wed., Dec. 15, 8–11 am
LL270 or RB184
- Covers entire semester:
 - ~ 50% E&M
 - ~ 50% waves & optics
- Equation sheet, notes on optics
supplied on exam (see web)
- Expect some questions from the
material covered in lecture

Physics 21
Fall, 2004

Equation Sheet

speed of light <i>in vacuo</i>	c	3.00×10^8 m/s	Planck's constant	h	6.626×10^{-34} J s
Gravitational constant	G	6.67×10^{-11} N m ² /kg ²	Planck's constant/(2π)	$\hbar = h/2\pi$	1.055×10^{-34} J s
Avogadro's Number	N_A	6.02×10^{23} mol ⁻¹	electron rest mass	m_e	9.11×10^{-31} kg
Boltzmann's constant	k_B	1.38×10^{-23} J/K	proton rest mass	m_p	1.6726×10^{-27} kg
charge on electron	e	1.60×10^{-19} C	neutron rest mass	m_n	1.6749×10^{-27} kg
free space permittivity	ϵ_0	8.85×10^{-12} C ² /N m ²	atomic mass unit	u	1.6605×10^{-27} kg
free space permeability	μ_0	$4\pi \times 10^{-7}$ T m/A		k	8.99×10^9 N m ² /C ²

$$\mathbf{F}_{12} = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r_{21}^3} (\mathbf{r}_1 - \mathbf{r}_2)$$

$$\mathbf{F} = q\mathbf{E}$$

$$d\mathbf{E} = \frac{4\pi}{\epsilon_0} \frac{dQ(\mathbf{r} - \mathbf{r}')}{|\mathbf{r} - \mathbf{r}'|^3}$$

$$\mathbf{E} = -\nabla V$$

$$\mathbf{E} = -\left(\hat{i} \frac{\partial V}{\partial x} + \hat{j} \frac{\partial V}{\partial y} + \hat{k} \frac{\partial V}{\partial z}\right)$$

$$V_b - V_a = -\int_a^b \mathbf{E} \cdot d\mathbf{l}$$

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$

$$u_{\text{elec}} = \frac{1}{2}\epsilon_0 E^2, u_{\text{mag}} = \frac{1}{2\mu_0} B^2$$

$$\text{Work} = \int \mathbf{F} \cdot d\mathbf{l}$$

$$Q = CV$$

$$C = \epsilon_0 K \frac{A}{d} = \epsilon \frac{A}{d}$$

$$U_{\text{cap}} = \frac{1}{2} CV^2 = \frac{1}{2} \frac{Q^2}{C}$$

$$U_{\text{ind}} = \frac{1}{2} LI^2$$

$$V = IR \text{ or } V - IR = 0$$

$$R = \rho \frac{l}{A} \quad \sigma = \frac{1}{\rho}$$

$$P = IV \quad P = I^2 R$$

$$E = \frac{\sigma}{\epsilon_0} \text{ parallel plate capacitor}$$

$$\mathbf{A} \times \mathbf{B} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

C 's in series or R 's in parallel:

$$\frac{1}{X_{\text{eff}}} = \frac{1}{X_1} + \frac{1}{X_2}$$

C 's in parallel or R 's in series:

$$X_{\text{eff}} = X_1 + X_2$$

$$X_R = R, X_L = \omega L, X_C = \frac{1}{\omega C}$$

$$RC \text{ time constant} = RC$$

$$LR \text{ time constant} = L/R$$

$Q(t)$ for RLC decay

$$Q_0 \exp(-Rt/2L) \cos \omega t$$

$$\omega^2 = \frac{1}{LC} - \frac{R^2}{4L^2}$$

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B} \text{ or } \mathbf{l} \times \mathbf{B}$$

$$d\mathbf{B} = \frac{\mu_0}{4\pi} \frac{Id\mathbf{l} \times (\mathbf{r} - \mathbf{r}')}{|\mathbf{r} - \mathbf{r}'|^3}$$

$$\text{field of long wire: } B = \frac{\mu_0 I}{2\pi R}$$

$$I = \frac{dQ}{dt}$$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}, \quad \frac{I_s}{I_p} = \frac{N_p}{N_s}$$

$$\chi_m = \frac{\mu}{\mu_0} - 1$$

$$\boldsymbol{\tau} = \boldsymbol{\mu} \times \mathbf{B} \quad \boldsymbol{\mu} = I\mathbf{A}$$

$$\text{solenoid } B = \mu_0 nI$$

$$\text{solenoid } L = \mu_0 N^2 A/l$$

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$$

$$\oint \mathbf{B} \cdot d\mathbf{A} = 0$$

$$\oint \mathbf{E} \cdot d\mathbf{l} = -\frac{d}{dt} \oint \mathbf{B} \cdot d\mathbf{A}$$

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I + \mu_0 \epsilon_0 \frac{d}{dt} \oint \mathbf{E} \cdot d\mathbf{A}$$

$$\sin(a \pm b) = \sin a \cos b \pm \cos a \sin b$$

$$\sin\left(\theta \pm \frac{\pi}{2}\right) = \sin \theta \cos \frac{\pi}{2} \pm \cos \theta \sin \frac{\pi}{2} = \pm \cos \theta$$

$$\cos(a \pm b) = \cos a \cos b \mp \sin a \sin b$$

$$\sin a + \sin b = 2 \cos \left(\frac{a-b}{2}\right) \sin \left(\frac{a+b}{2}\right)$$

$$C = 2\pi r \quad \text{circumference of circle}$$

$$C = \pi d \quad \text{circumference of circle}$$

$$A = \pi r^2 \quad \text{area of circle}$$

$$A = 4\pi r^2 \quad \text{surface area of sphere}$$

$$V = \frac{4}{3}\pi r^3 \quad \text{volume of sphere}$$

$$ax^2 + bx + c = 0 \Rightarrow$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\int \frac{du}{\sqrt{a^2 + u^2}} = \ln(u + \sqrt{a^2 + u^2})$$

$$\int \frac{u du}{\sqrt{a^2 + u^2}} = \sqrt{a^2 + u^2}$$

$$\int \frac{du}{a^2 + u^2} = \frac{1}{a} \tan^{-1} \left(\frac{u}{a}\right)$$

$$\int \frac{u du}{a^2 + u^2} = \frac{1}{2} \ln(a^2 + u^2)$$

$$\int \frac{du}{(a^2 + u^2)^{3/2}} = \frac{u}{a^2 \sqrt{a^2 + u^2}}$$

$$\int \frac{u du}{(a^2 + u^2)^{3/2}} = -\frac{1}{\sqrt{a^2 + u^2}}$$

$$\int e^{au} du = \frac{1}{a} e^{au}$$

$$\int \ln u du = u \ln u - u$$

$$\int u^n du = \frac{1}{n+1} u^{n+1}$$

$$\int \frac{du}{a+bu} = \frac{1}{b} \ln(a+bu)$$

$$\int \frac{du}{u} = \ln u$$

$$\int_0^{2\pi} \cos^2 \theta d\theta = \int_0^{2\pi} \sin^2 \theta d\theta = \pi$$

$$v = \sqrt{T/\rho} \quad (T=\text{tension})$$

$$v = (348 \text{ m/s}) \sqrt{T/300}$$

$$v = f\lambda$$

$$T = 1/f \quad (T=\text{period})$$

$$\omega = 2\pi f \quad k = 2\pi/\lambda$$

$$\langle P \rangle = \frac{1}{2} \rho A^2 \omega^2 v$$

$$\frac{\partial^2 D}{\partial x^2} = \frac{1}{v^2} \frac{\partial^2 D}{\partial t^2}$$

$$\mathbf{S} = \frac{1}{\mu_0} (\mathbf{E} \times \mathbf{B})$$

$$\bar{S} = \frac{1}{2} \epsilon_0 c E_0^2 = \frac{1}{2} \frac{c}{\mu_0} B_0^2$$

$$= \frac{E_0 B_0}{2\mu_0} = \frac{E_{\text{rms}} B_{\text{rms}}}{\mu_0}$$

$$c = 1/\sqrt{\epsilon_0 \mu_0}$$

$$\mathbf{E} \times \mathbf{B} \propto \mathbf{v} \quad (\text{plane wave})$$

$$\Delta x \Delta p \gtrsim \hbar \quad (\hbar = h/2\pi)$$

$$\lambda = h/p \quad (\text{de Broglie})$$

$$-\frac{\hbar^2}{2M} \frac{\partial^2 \psi}{\partial x^2} = i\hbar \frac{\partial \psi}{\partial t}$$

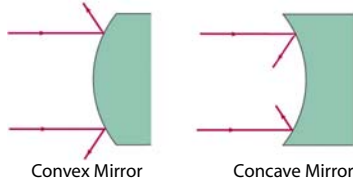
$$\text{KE} = p^2/(2M)$$

$$p = \hbar k \quad E = \hbar \omega$$

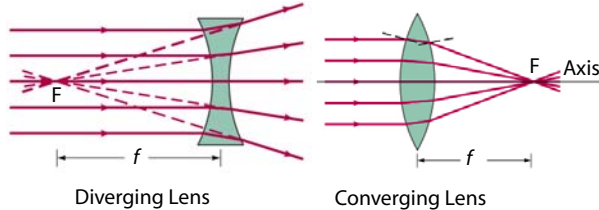
$$e^{i\theta} = \cos \theta + i \sin \theta$$



Mirror Types:



Lens Types:



The Mirror Equation:

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

- f is positive for concave mirrors and negative for convex mirrors.
- When the object, image, or focal point is on the reflecting side of the mirror, the corresponding distance is positive. If any of these points is behind the mirror, the corresponding distance is negative.
- h_i is positive if the image is upright, negative if inverted.

The Lens Equation:

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

- f is positive for converging lenses and negative for diverging lenses.
- d_o is positive if object is on the side of the lens from which the light comes; otherwise negative.
- d_i is positive if it is on the opposite side of the lens from which the light comes; otherwise negative. Equivalently, d_i is positive/negative for a real (virtual) image.
- h_i is positive if the image is upright, negative if inverted.

Ray Tracing for Lenses and Mirrors:

- Ray 1 is parallel to the axis; after reflection/refraction it must pass through F . For a lens, you must determine which of the two F 's the ray passes through.
- Ray 2 or its extension passes through the appropriate F and reflects/refracts so that it is parallel to the axis.
- Ray 3 passes through the center of curvature of a mirror or the center of a lens.

Refraction at a Spherical Surface:

$$\frac{n_1}{d_o} + \frac{n_2}{d_i} = \frac{n_2 - n_1}{R}$$

Snell's Law:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

Total internal reflection:

$$\sin \theta_c = \frac{n_1}{n_2} \quad (n_1 < n_2)$$

Lensmakers Equation:

$$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

Focal ratio:

Lens or mirror diameter D is often expressed using the focal ratio or f -number:

$$f\text{-number} = f/D$$

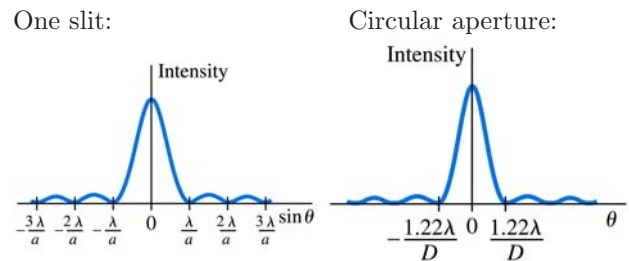
Magnification of an Astronomical Telescope:

$$M = -f_o/f_e$$

Interference:

$$d \sin \theta = \begin{cases} m\lambda & \text{constructive} \\ (m + \frac{1}{2})\lambda & \text{destructive} \end{cases}$$

Diffraction Patterns:



The diagram for one slit contains essentially the same information as the equation that $a \sin \theta = m\lambda$ for a minima.

Phase change:

When light propagates from one medium (n_1) to another (n_2), there is a 180° phase change in the reflected wave if $n_2 > n_1$.

Polarization:

$$I = I_0 \cos^2 \theta$$