2DL Physics Laboratory–Modern Physics
Spring 2009 Schedule

week (starts)	lecture	exp	hw
1 (30 March)	light as a wave; Exp 1. Optical Spectra and Diffraction Grating		
2 (6 April)	the Michelson-Morley experiment; Exp 2. Coherence of Light and Interferometer		probs from Taylor due at lecture:
3 (13 April)	blackbody radiation; Plank's law; photoelectric effect; light quantization;	1-6 demo	
4 (20 April)	light as a particle; the Compton effect; Exp 3. The Photoelectric Effect 	1-4	3.10 & 3.28
5 (27 April)	electron as a particle; the Thomson experiment on e/m; Exp 4. e/m of the Electron 	1-4	4.18 & 4.26
6 (4 May)	the Rutherford model of the atom; the Bohr atom; spectral series;	1-4	5.20 & 5.36
7 (11 May)	Exp 5. The Frank-Hertz experiment 	1-4	7.2 & 8.10
8 (18 May)	matter waves; wave packets; electron as a wave; the Heisenberg uncertainty principle; Exp 6. Electron Diffraction 	5-6	9.14 & 12.3
9 (25 May)	holiday	5-6	
10 (1 June)	final	make-up	

Required:
John R. Taylor, *An Introduction to Error Analysis*, 2nd Ed., 1997.
Laboratory Manual, Physics 2DL.
Notebooks (lab): Two 7 7/8 x 10 1/8 quadrille ruled notebooks
(You will work with one notebook while the other one is being reviewed by the TA).
Calculator: Better a scientific calculator with a statistical analysis package
(mean, standard deviation, and linear regression).

Recommended:
R.A. Serway, C.J. Moses, C.A. Moyer, Modern Physics, 3d edition (2005)

http://physics.ucsd.edu/students/courses/spring2009/managed/physics2dl/

Grading Policy:

Lab Work	6x12=72%
Homework	10x1=10%
Exam	18%

problems on error analysis
similar to hw problems
and lecture examples

lab questions
related problems,
derivation of background theory,
sketching of apparatus and circuits,
and description of results

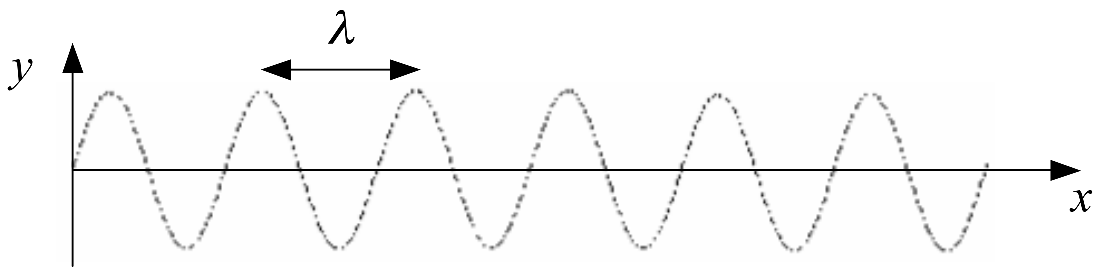
EXPERIMENT #1
Optical Spectra and the Diffraction Grating

GOALS
Physics
Use an optical grating to find the dominant spectral lines from gas discharge tubes.
Identify an unknown gas from the observed spectrum.

Errors
Calibrate the grating by comparison to known spectra.
Use error propagation to relate angle measurement uncertainties to wavelength uncertainties.

References
Serway, Moses, Moyer §3.1-3.3

Waves



displacement $y = A\cos\left(\frac{2\pi}{\lambda}x - 2\pi ft + \phi\right) = A\cos(kx - \omega t + \phi)$

wave frequency f

wavelength λ

phase velocity $v_p = \lambda f$

phase ϕ

angular frequency $\omega = 2\pi f$

wavenumber $k = \frac{2\pi}{\lambda}$

phase velocity $v_p = \frac{\omega}{k}$

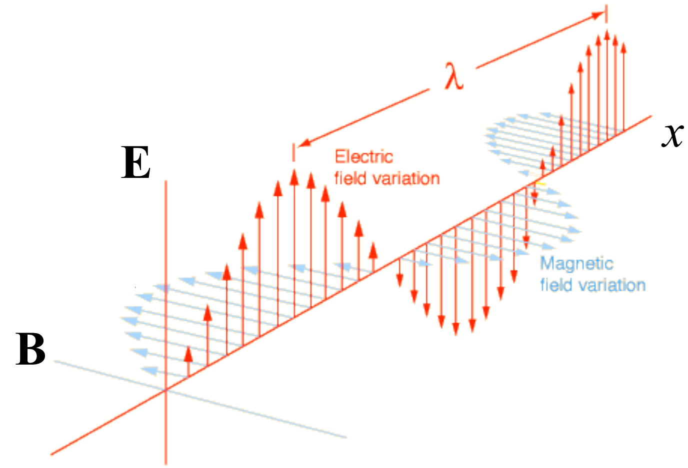
Transverse Electromagnetic Waves

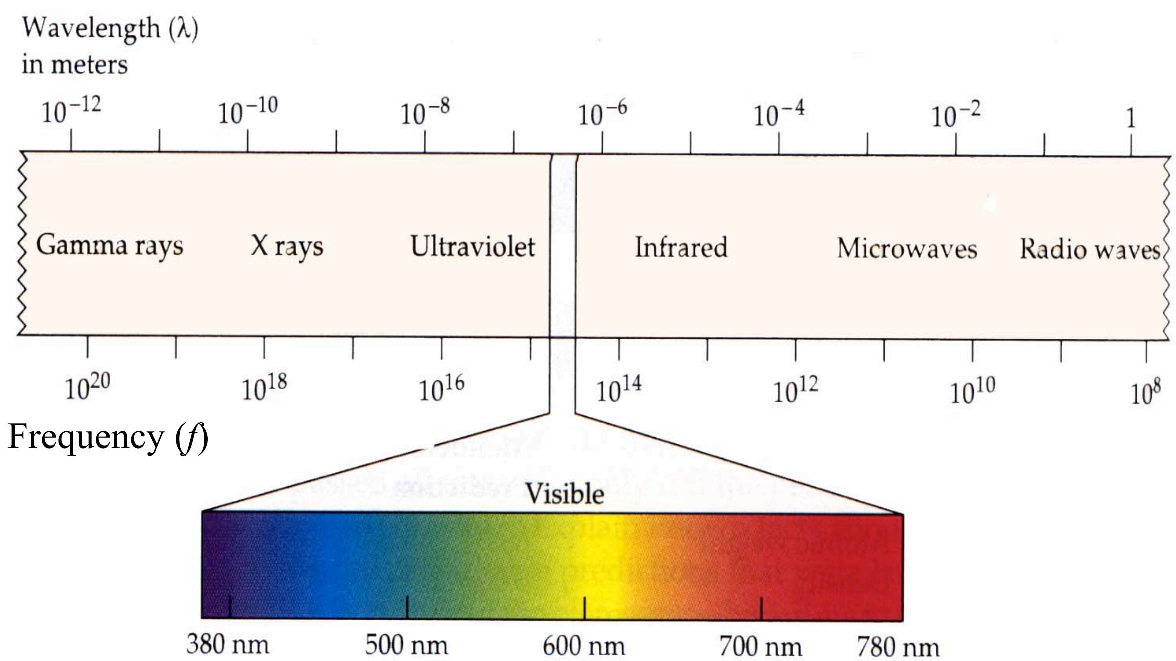
electromagnetic wave equation in vacuum
for a wave propagating along *x*

$$\frac{\partial^2 E}{\partial t^2} = c^2 \frac{\partial^2 E}{\partial x^2}$$

$$E = A\cos(kx - \omega t + \phi)$$

$$v_p = \frac{\omega}{k} = \lambda f = c = 2.998 \times 10^8 \text{ m/s}$$





Constructive and Destructive Interference

consider two waves with same λ
same λ means same k and same ω

$k = 2\pi/\lambda \qquad \omega = ck = 2\pi c/\lambda$

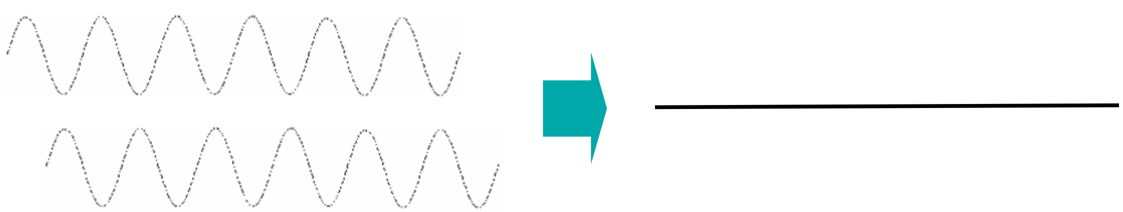
$$E_1 = A\cos(kx - \omega t + \phi_1)$$
$$E_2 = A\cos(kx - \omega t + \phi_2)$$

phase difference

waves in phase $\quad \phi_1 - \phi_2 = 0 + 2\pi n \qquad E = E_1 + E_2 = E_1 + E_1 = 2A\cos(kx - \omega t + \phi_1)$

constructive interference

waves out of phase $\quad \phi_1 - \phi_2 = \pi + 2\pi n \qquad E = E_1 + E_2 = E_1 - E_1 = 0$



destructive interference

Diffraction Grating

$$E_1 = A\cos(kx - \omega t + \phi_1)$$

$$E_2 = A\cos\left(k\left[x - d\sin\theta\right] - \omega t + \phi_1\right)$$

...

$$E_{m+1} = A\cos\left(k\left[x - md\sin\theta\right] - \omega t + \phi_1\right)$$

$$E_1 = A\cos(kx - \omega t + \phi_1)$$

$$E_2 = A\cos(kx - \omega t + \left[\phi_1 - kd\sin\theta\right])$$

...

$$E_{m+1} = A\cos(kx - \omega t + \left[\phi_1 - kmd\sin\theta\right])$$

phase difference

$$\phi_m - \phi_{m+1} = kd\sin\theta = \frac{2\pi}{\lambda}d\sin\theta$$

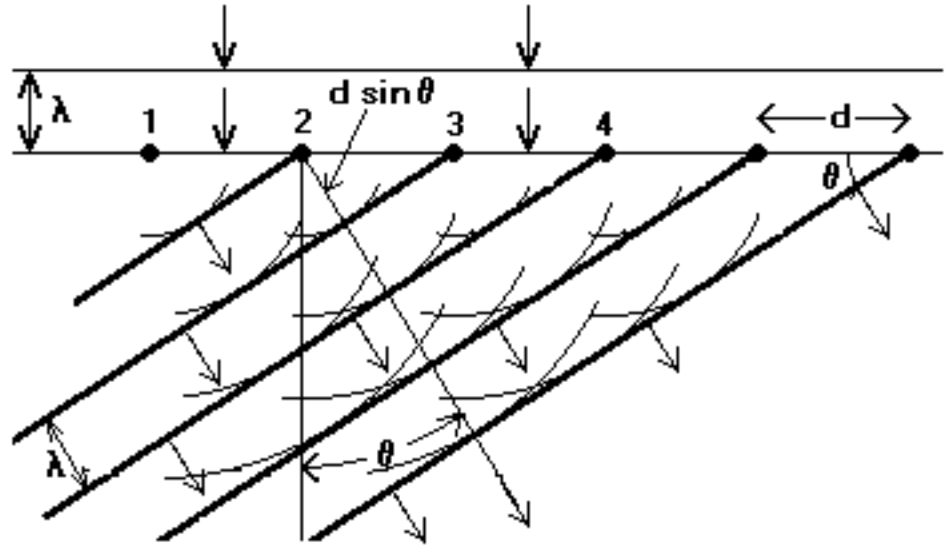
interference is constructive if

$$\phi_m - \phi_{m+1} = 2\pi n$$

$$\frac{2\pi}{\lambda}d\sin\theta = 2\pi n$$

$$d\sin\theta = n\lambda$$

the incident wave crests, which are planes where the wave is maximal



the wave is effectively re-radiated separately by each point of grating slit, forming circular wave crests

a plane wave (with wavelength λ)
incident normally onto a diffraction grating
(with spacing d)
will be diffracted to angles θ given by

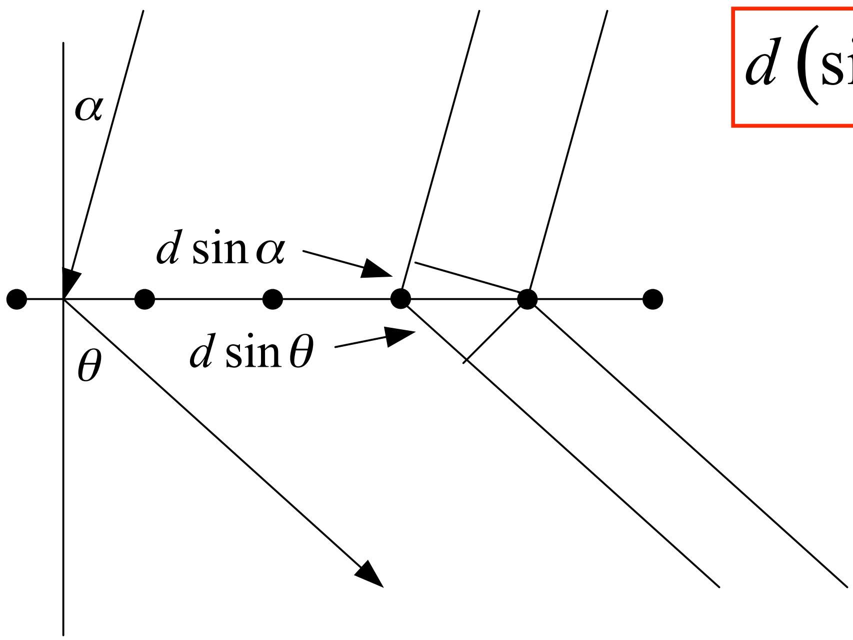
$$d\sin\theta = n\lambda$$

where n = 1,2, ... is the "order" of the diffraction peak

The grating equation

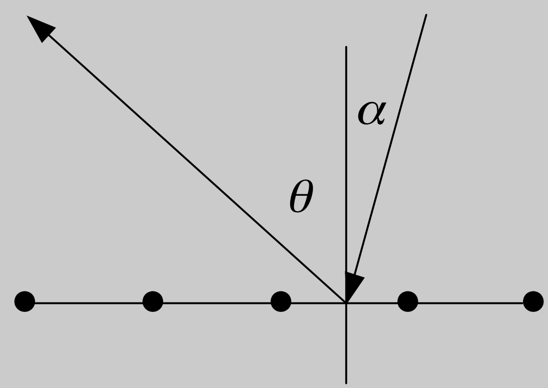
if the plane wave is incident at an angle α
with respect to the perpendicular to the grating,
then the constructive interference peaks occur at angles θ given by

$$d\left(\sin\alpha + \sin\theta\right) = n\lambda$$



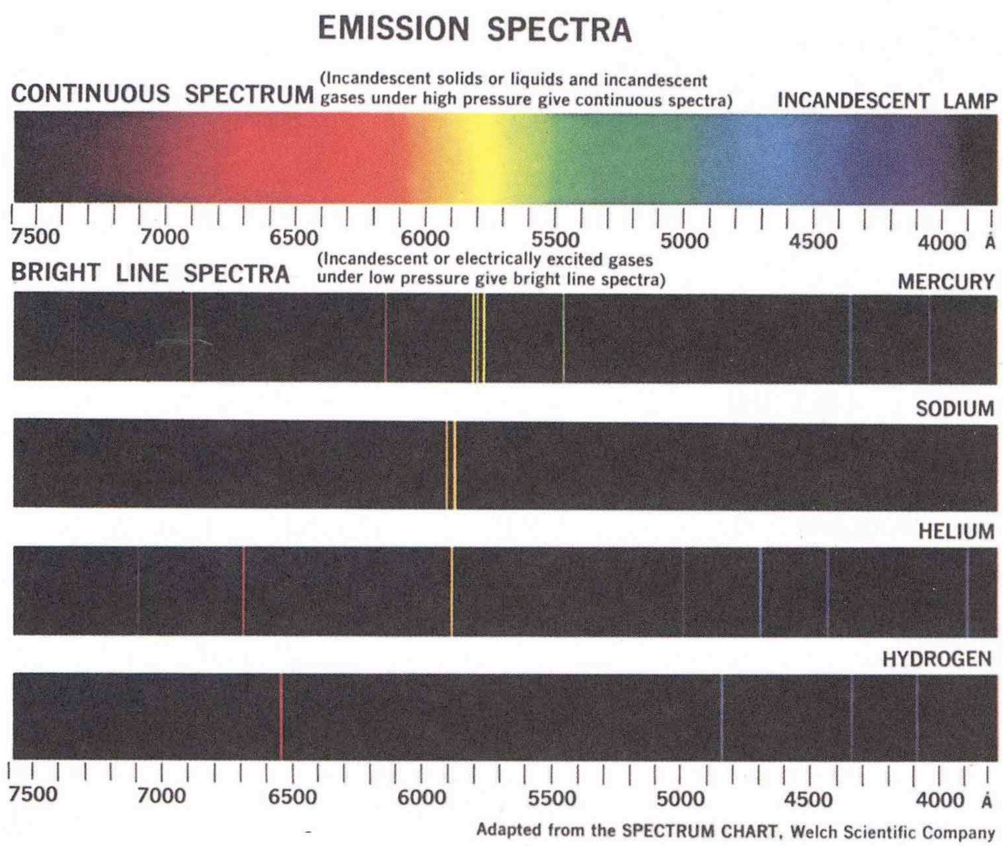
for reflecting gratings

$$d\left(\sin\alpha - \sin\theta\right) = n\lambda$$



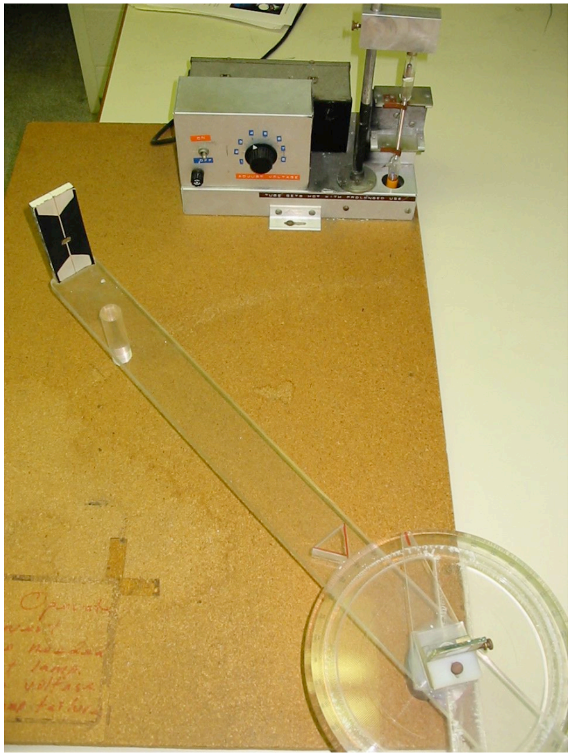
diffraction grating allows measuring of λ
by measuring θ

spectrum measurement



elemental substance identifies itself uniquely by the light it emits when it is in a very hot environment

The experiment

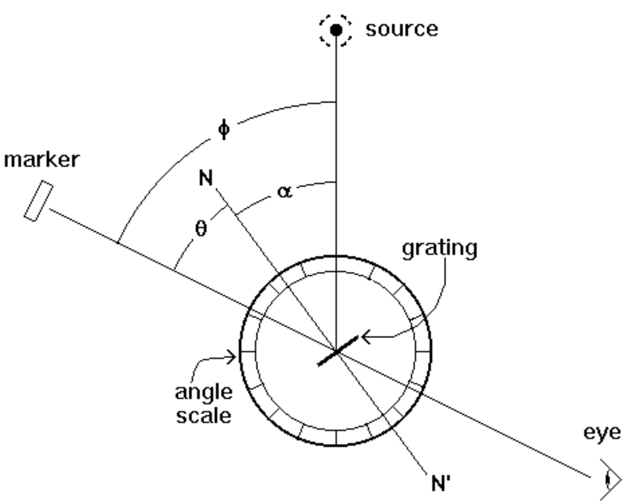


Equipment

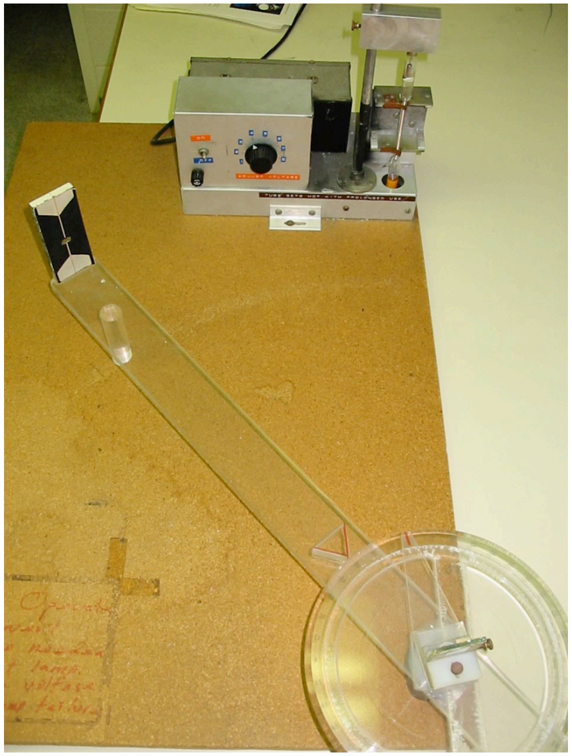
1. Samples of gases in glass “discharge tubes.” Some tubes contain a known gas and three tubes contain “unknown gases”.
2. High voltage power supply to produce the electrical discharge within the sample tubes.
3. Diffraction grating with d=1016 nm.
4. Grating support and marker for locating the spectral lines.
5. Table of emission wavelengths (and strengths) for a few common elements, including the unknown gases.

When you look through the grating illuminated by one of the discharge tube sources, you will notice a set of colored spectral lines, and the “marker” allows the angles to be measured. Each colored line corresponds to one of the components of the emission spectrum for the gas in the tube.

The "first-order" set of spectral line images, corresponding to n = 1 in the grating equation, will be seen at the smallest angles ϕ (closest to the source itself). At larger angles ϕ you will probably see another set of lines similar to the first; this is the "second-order" spectrum corresponding to n =2.



The experiment



DO NOT TOUCH the sample tube with the 5kV power supply ON.

Before mounting or changing one of the discharge tubes be sure that the power supply switch is off.

The sample tubes have a small glass projection sticking out perpendicularly near one end. When changing sample tubes, be sure that this projection is at the top end of the tube.

Turn the supply off when not actually in use, to preserve the tubes which have a rather limited lifetime.

The experiment

Measurements:

1. Verify and calibrate your spectrometer, by measuring Hg and Ne.
Measure 5 or more separate lines for each gas (j=1, 2, ..., 5).
For each line, make 4 separate measurements (2 each partner)
Measure α and θ, estimate $\delta\alpha$ and $\delta\theta$
Calculate λ, $\delta\lambda$, *presuming* d = 1016 nm. Obtain $\overline{\lambda}_j \pm \delta\overline{\lambda}_j$

Plot $\overline{\lambda}_j$ vs $\overline{\lambda}_j^{theory}$, with error bars, using different symbols for Hg and Ne.
Obtain your best estimate of d for your grating.

2. For 3 "unknown" tubes,
   Obtain $\overline{\lambda}_j \pm \delta\overline{\lambda}_j \quad (j = 1, 2, 3)$.
   Identify the gas.

3. For 1 known tube, observe 2nd order lines λ_j, and compare to the Grating Equation.