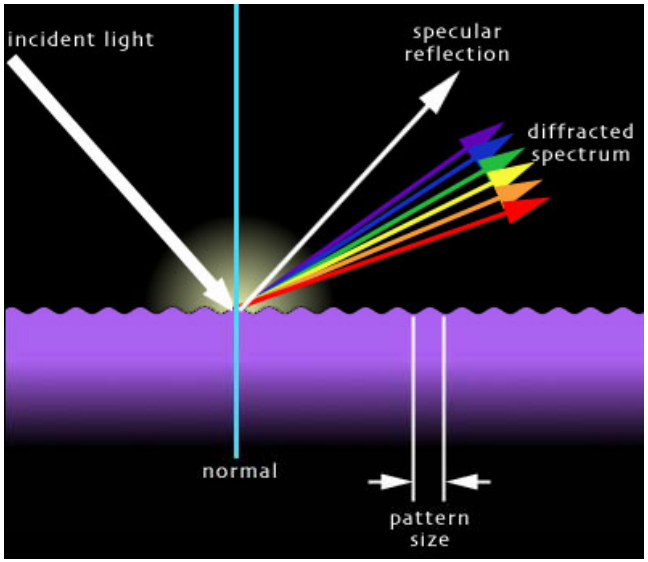
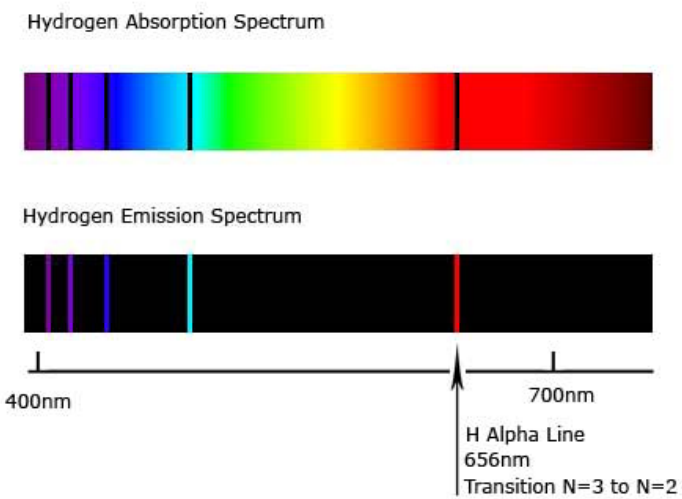
Grating Spectrometers and Atomic Spectroscopy of Hydrogen, Deuterium, and Helium

Week of March 1, 2010

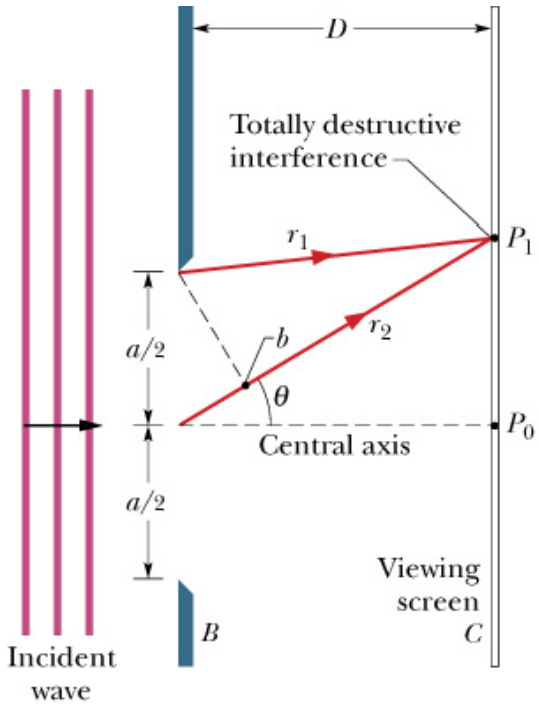




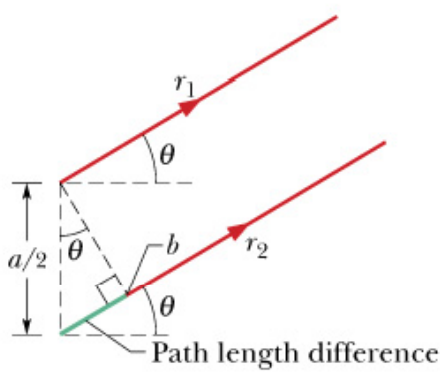
Modern Physics Laboratory (Physics 6180/7180)

The University of Toledo
Instructor: Randy Ellingson

Diffraction by a Single Slit: Locating the *Minima*



(a)



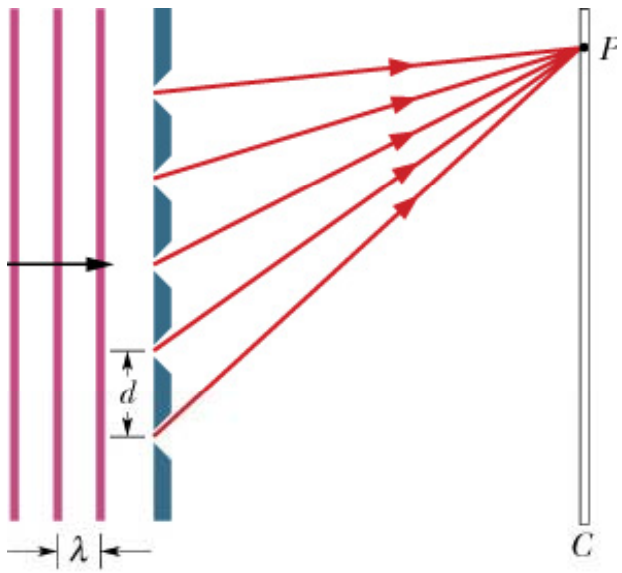
(b)

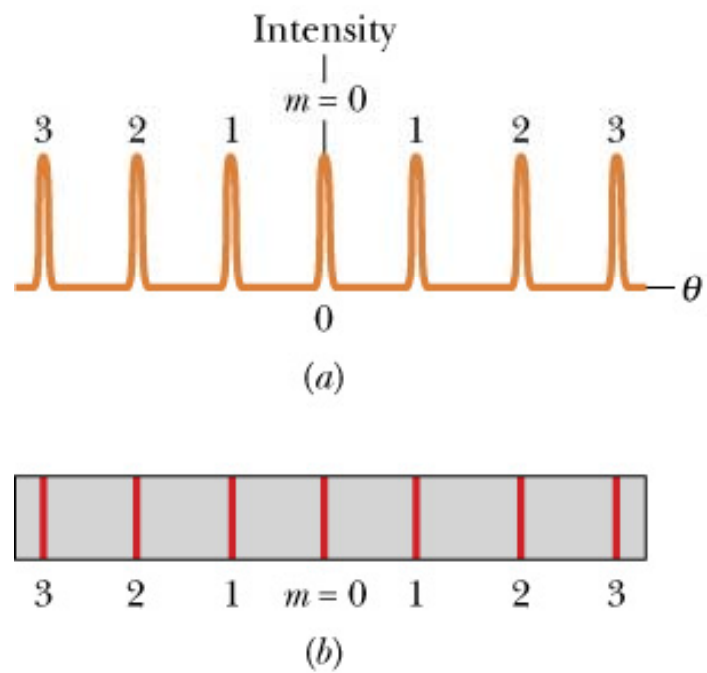
When the path length difference between rays r_1 and r_2 is $\lambda/2$, the two rays will be out of phase when they reach P_1 on the screen, resulting in destructive interference at P_1. The path length difference is the distance from the starting point of r_2 at the center of the slit to point *b*.

For $D >> a$, the path length difference between rays r_1 and r_2 is $(a/2) \sin \theta$.

Diffraction Gratings

Device with *N* slits (rulings) can be used to manipulate light, such as separate different wavelengths of light that are contained in a single beam. How does a diffraction grating affect monochromatic light?

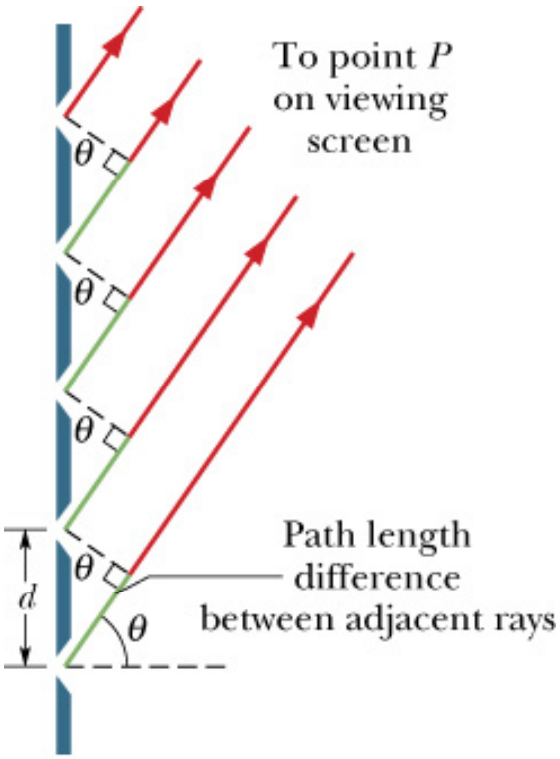


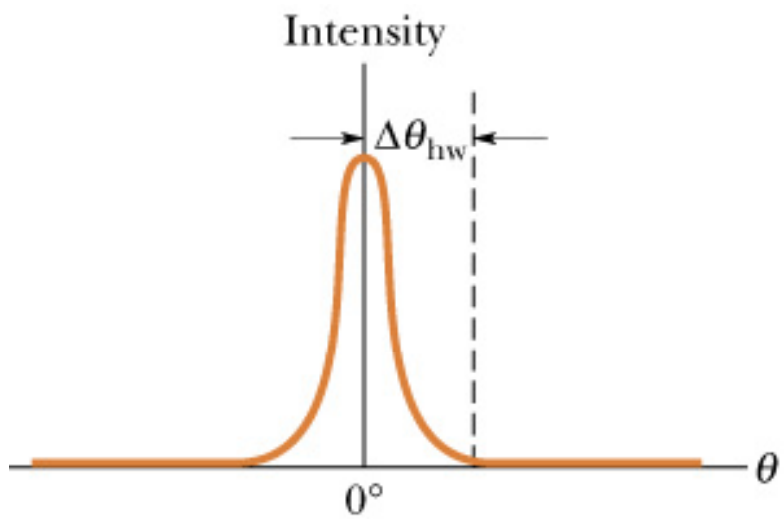


$$d \sin\theta = m\lambda \quad \text{for } m = 0, 1, 2\ldots \quad \text{(maxima-lines)}$$

Width of Lines

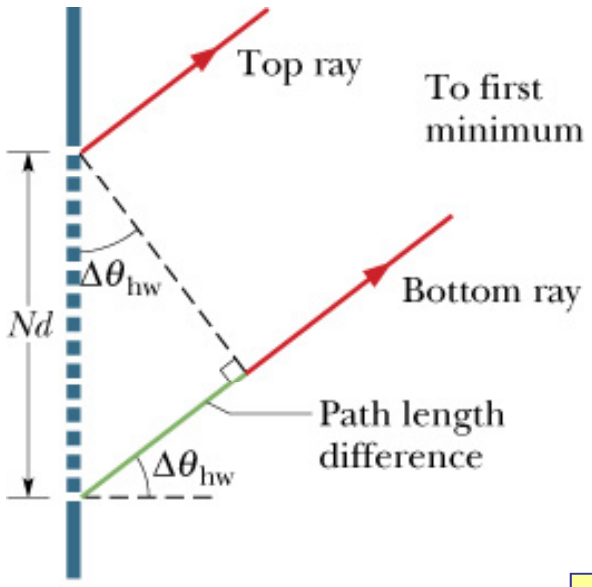
The ability of the diffraction grating to resolve (separate) different wavlength depends on the width of the lines (maxima)





Width of Lines, cont'd

In this course, a sound wave is roughly defined as any longitudinal wave (particles moving along the direction of wave propagation).



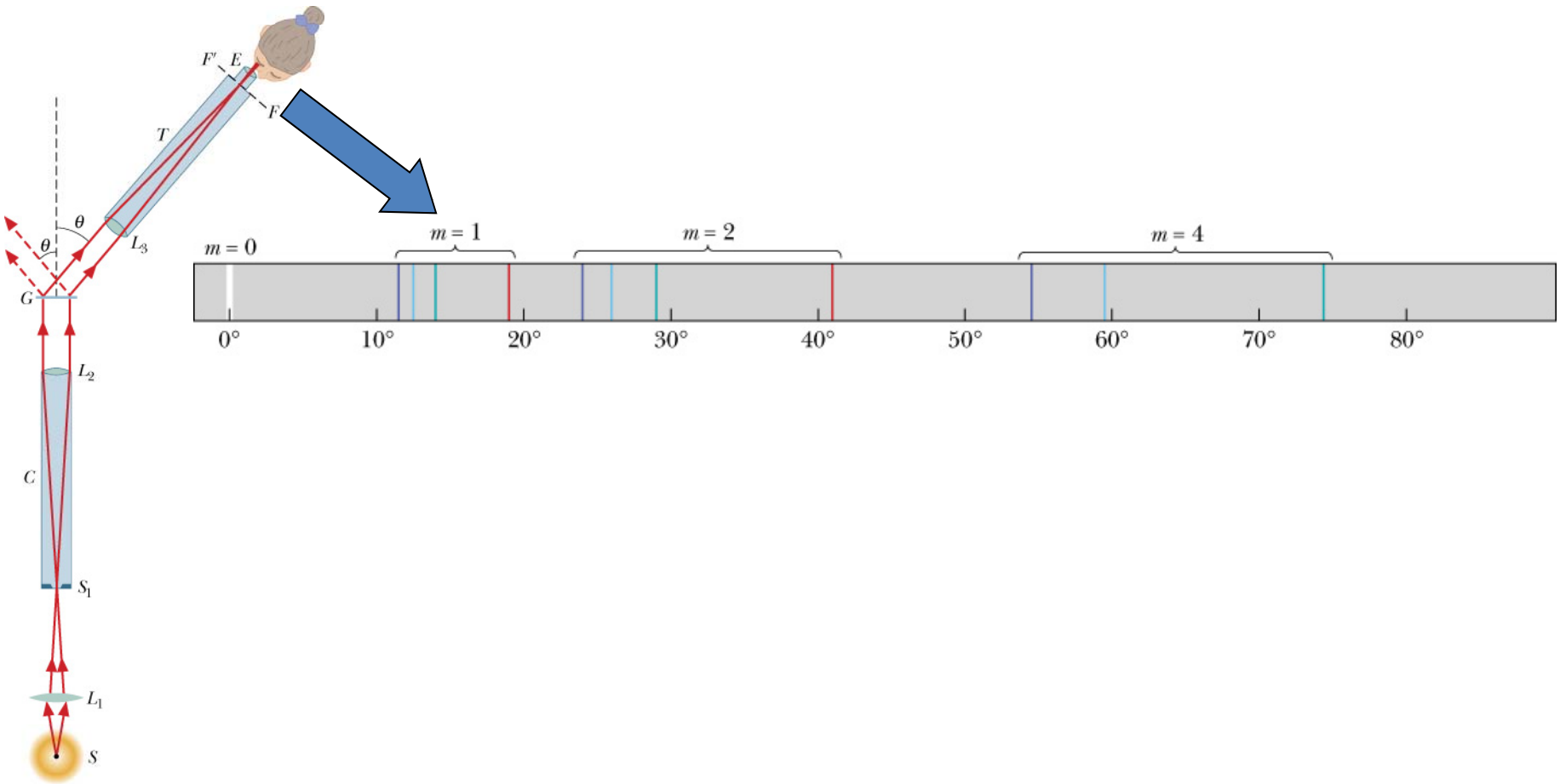
$$Nd \sin \Delta\theta_{\text{hw}} = \lambda \quad , \qquad \sin \Delta\theta_{hw} \approx \Delta\theta_{hw}$$

$$\Delta\theta_{\text{hw}} = \frac{\lambda}{Nd} \quad \text{(half width of central line)}$$

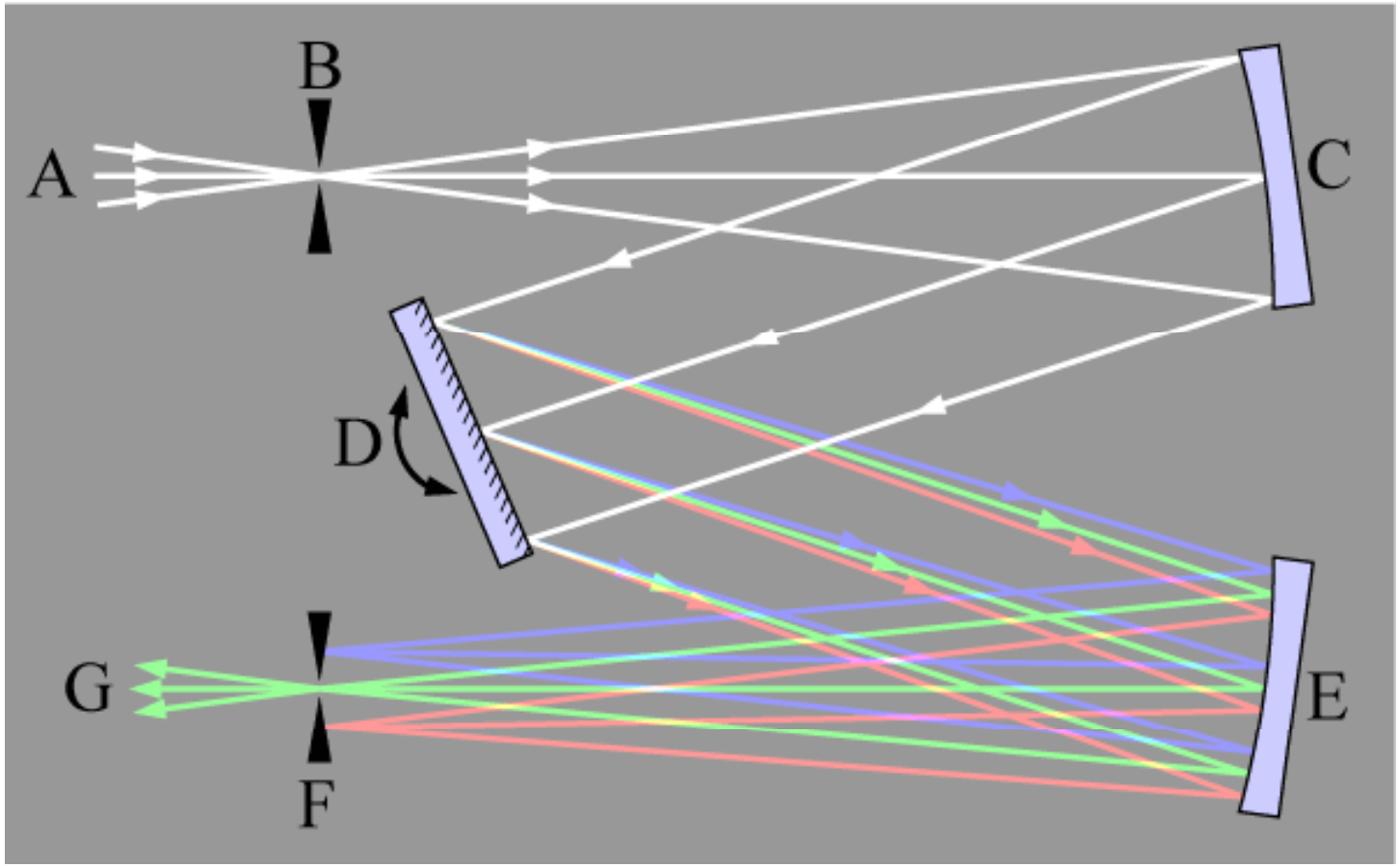
$$\boxed{\Delta\theta_{\text{hw}} = \frac{\lambda}{Nd\cos\theta} \quad \text{(half width of line at } \theta\text{)}}$$

Grating Spectroscope

Separates different wavelengths (colors) of light into distinct diffraction lines



Czerny-Turner Monochrometer



Grating equation

http://www.cis.rit.edu/class/simg401/DiffractionGratingEquation.pdf

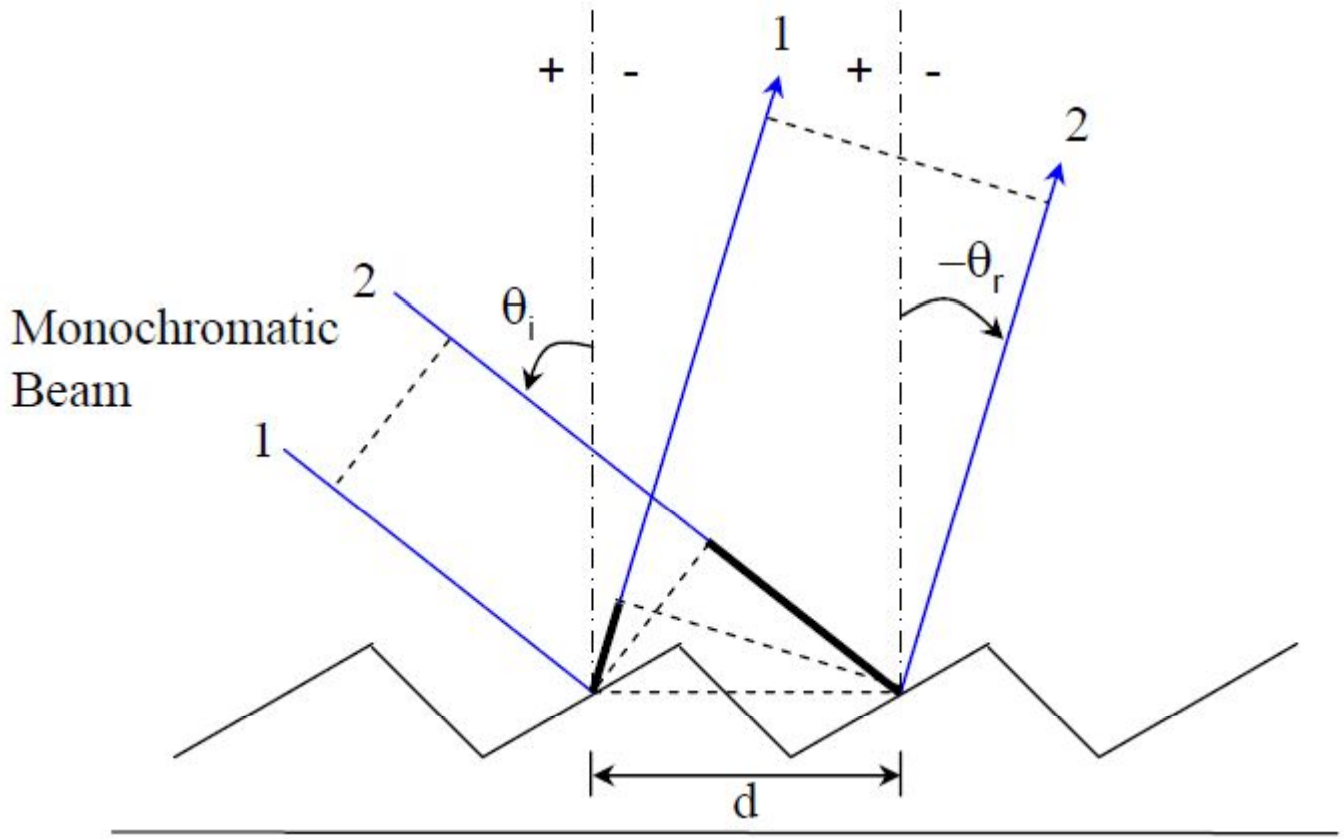
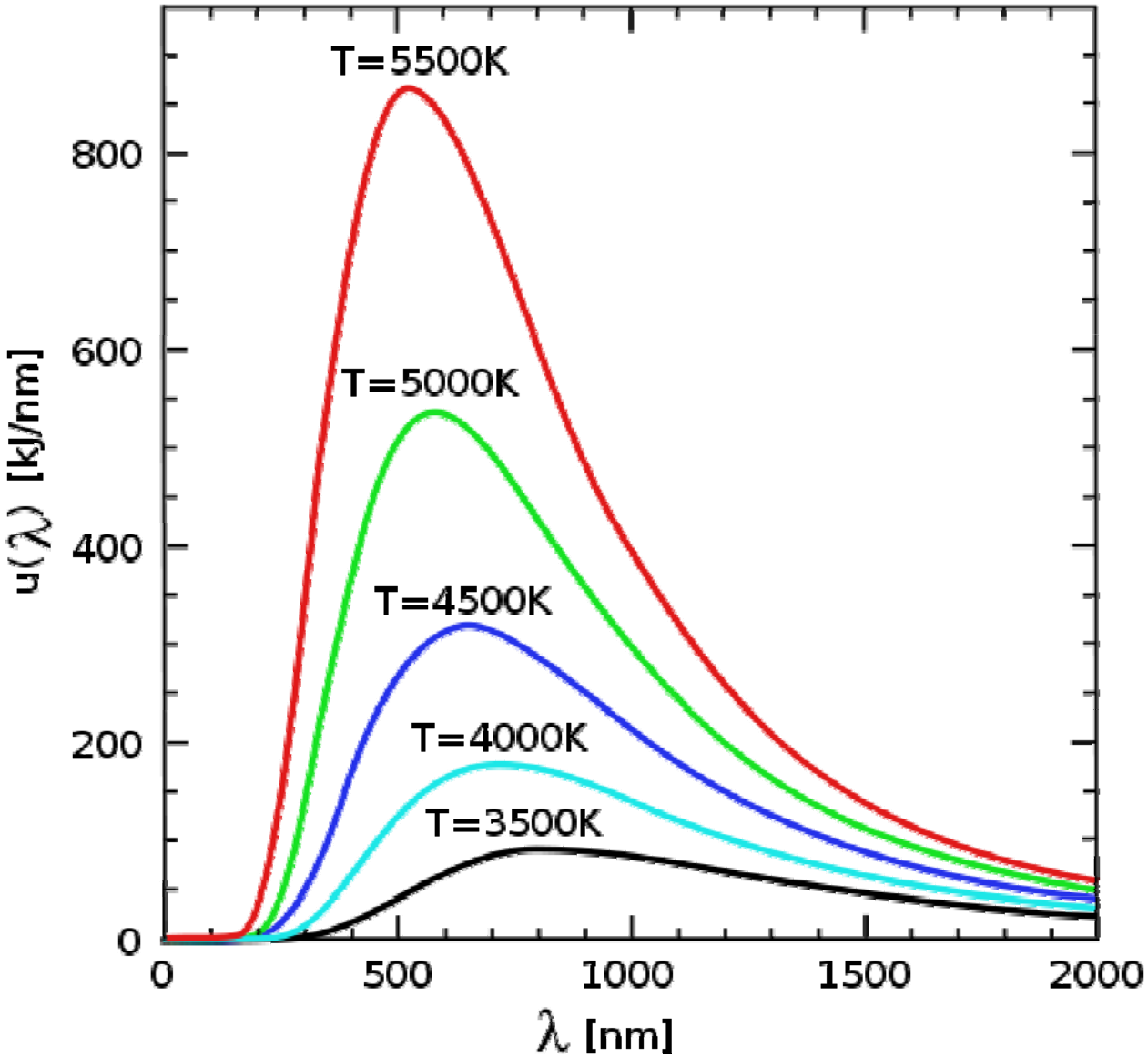
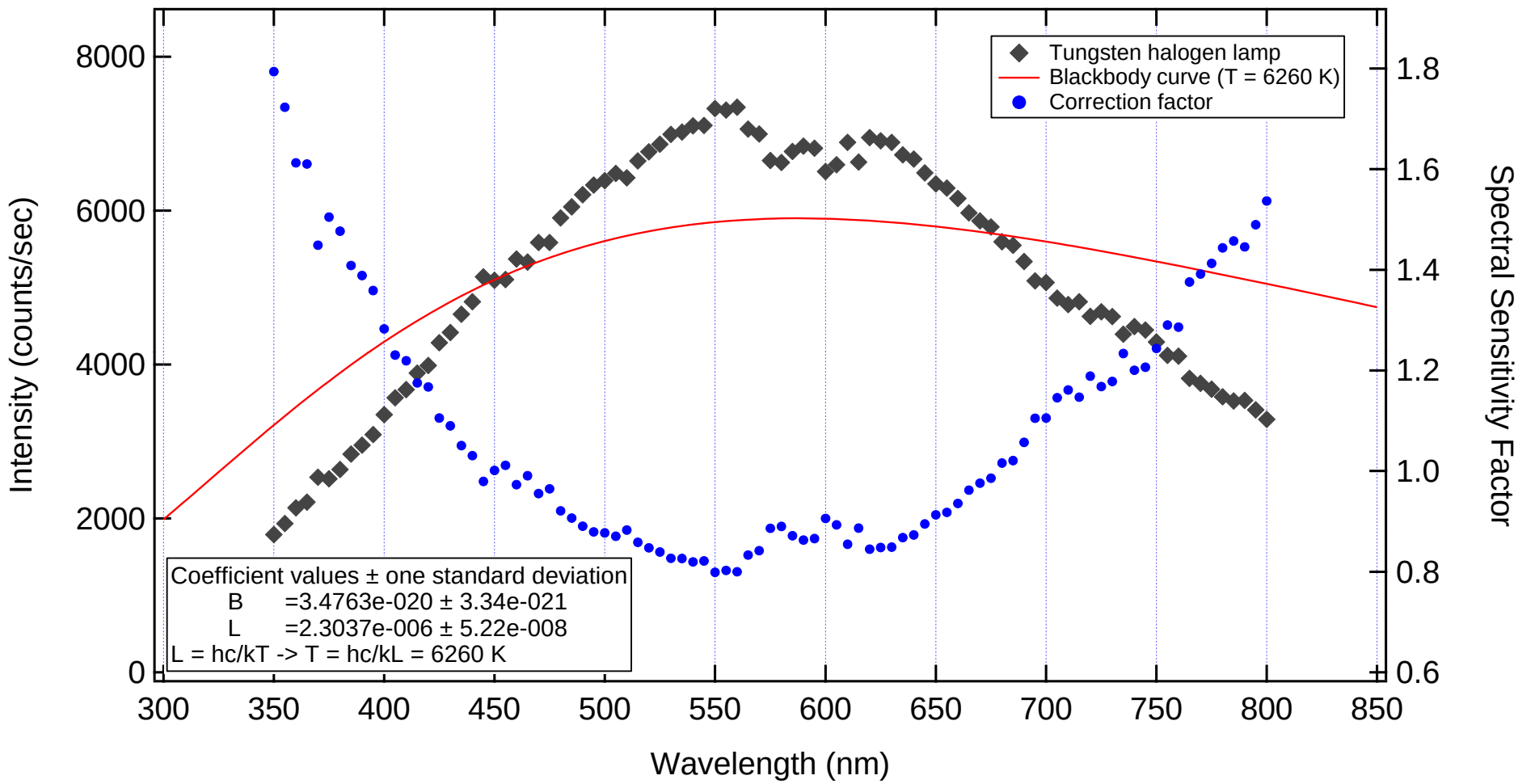


Figure 1: Monochromatic beam incident on (blazed) diffraction grating at angle θ_i and diffracted at angle $-\theta_r$. The blaze spacing is d.

Spectrometer sensitivity calibration: grating efficiency, PMT sensitivity



Spectrometer sensitivity calibration (continued)



spectral photon flux (units of *photons/(time-area-Δλ)*):

$$\frac{dN}{dt} \propto \frac{B}{\lambda^4 (e^{hc/\lambda kT} - 1)}$$

Hydrogen atom (Bohr model)

$$E_n = -\frac{\mu Z^2 e^4}{2(4\pi\varepsilon_0)^2 \hbar^2}\frac{1}{n^2}$$

Hydrogen atom energy levels

$$\alpha = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{\hbar c} \cong \frac{1}{137}$$

Fine structure constant

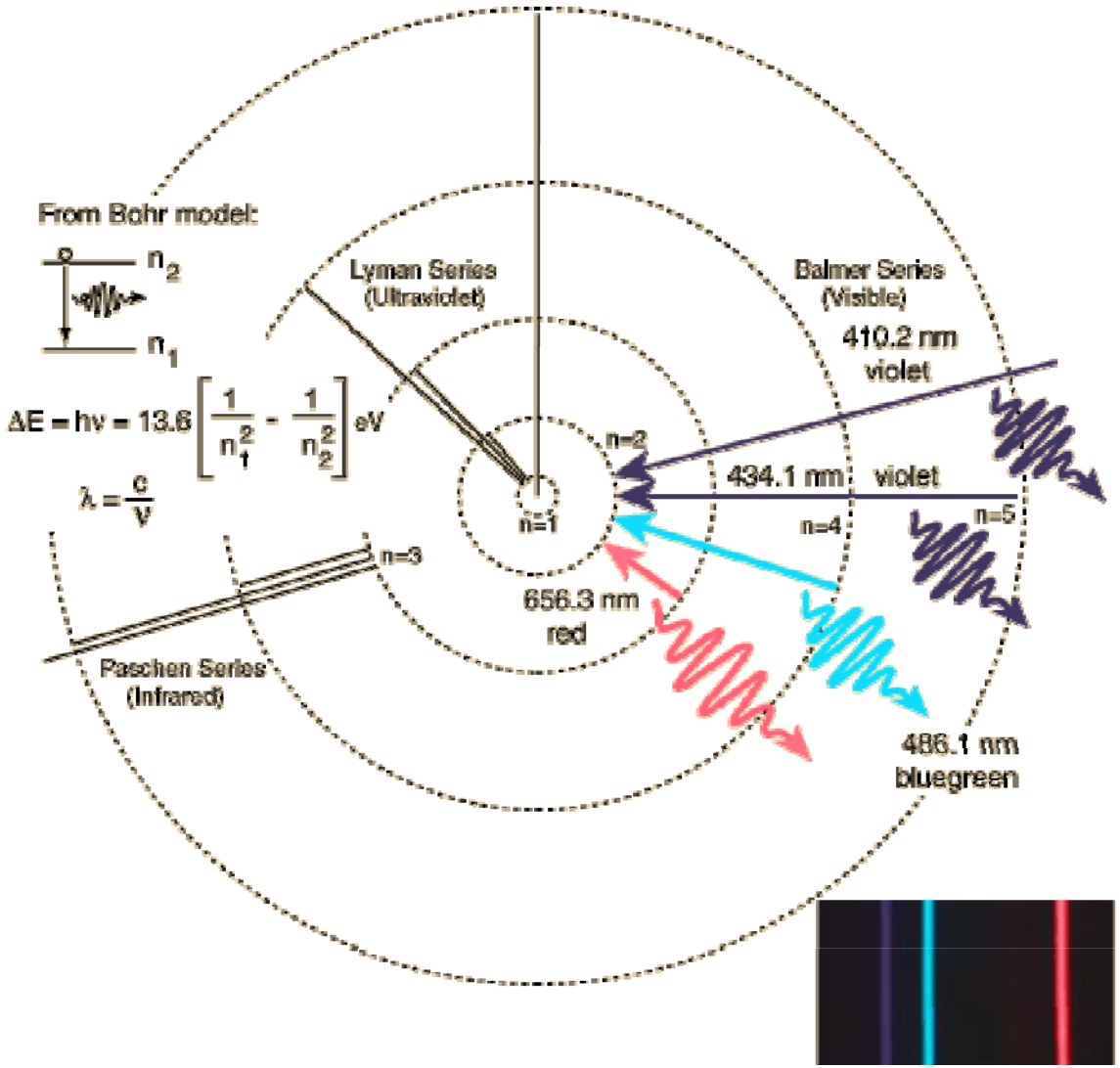
$$E_n = -\frac{\mu\alpha^2 c^2}{2}\frac{1}{n^2}$$

Incorporating reduced mass

$$\mu = \frac{m_e M}{m_e + M}$$

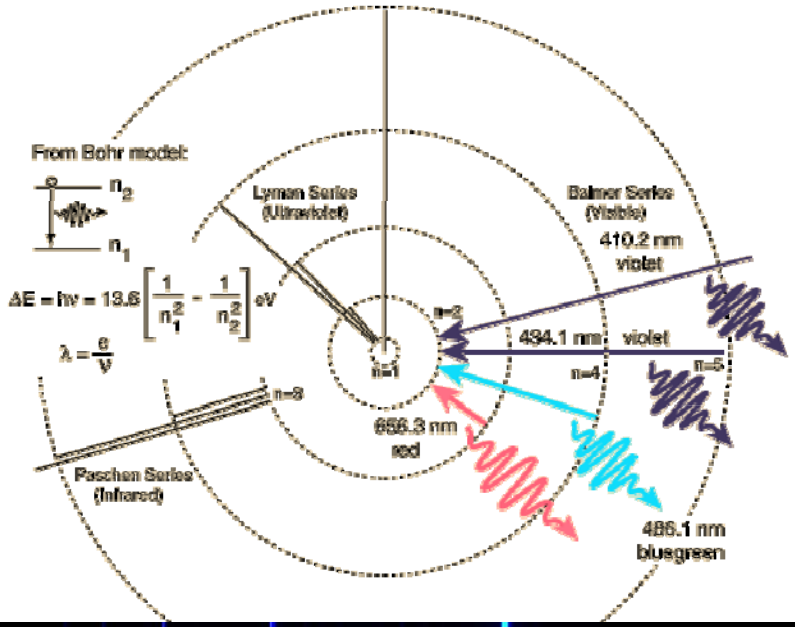
Reduced mass

Hydrogen spectrum



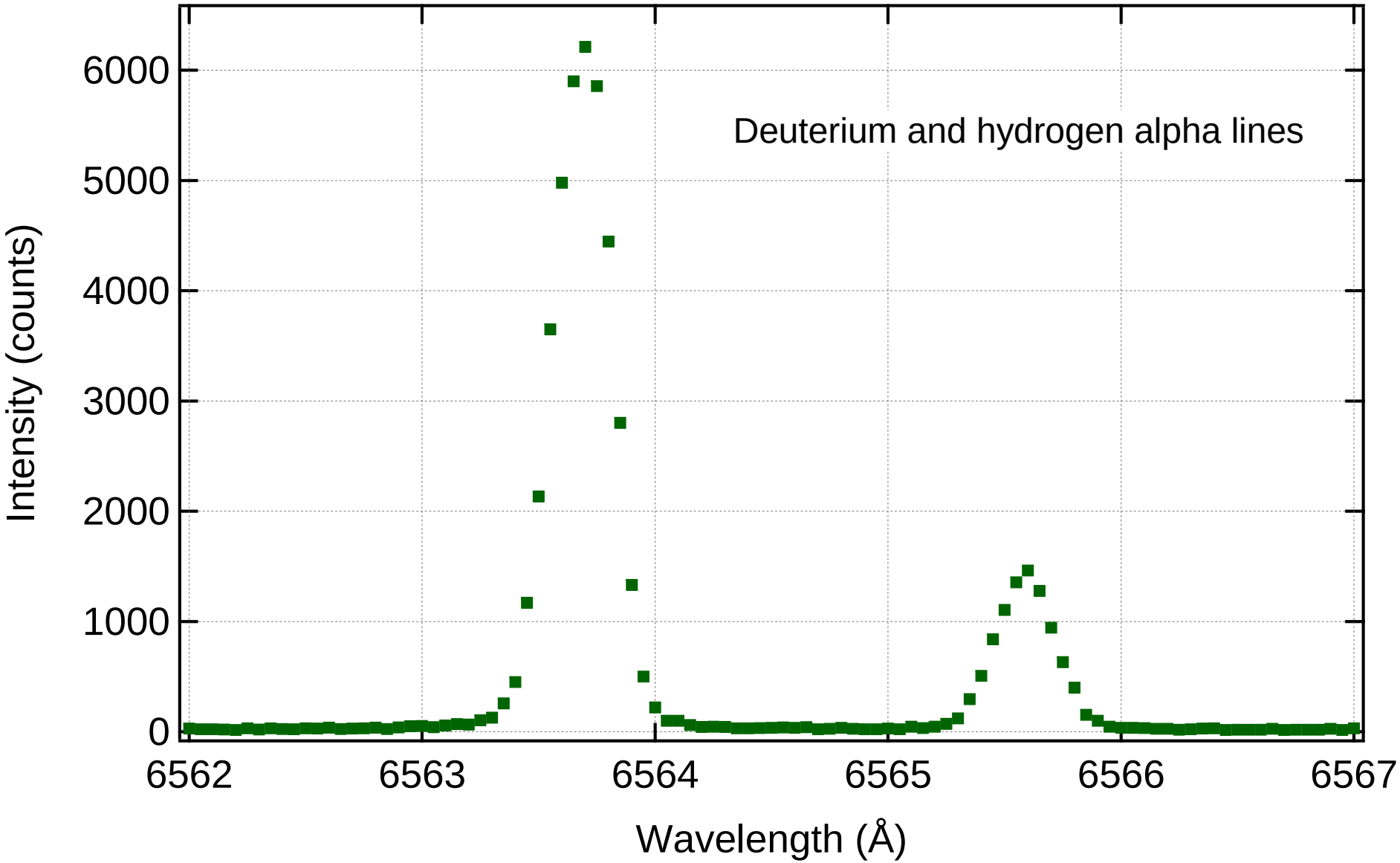
From http://hyperphysics.phy-astr.gsu.edu/hbase/hyde.html#c4

Hydrogen spectrum



Balmer series (transitions ending at n = 2)

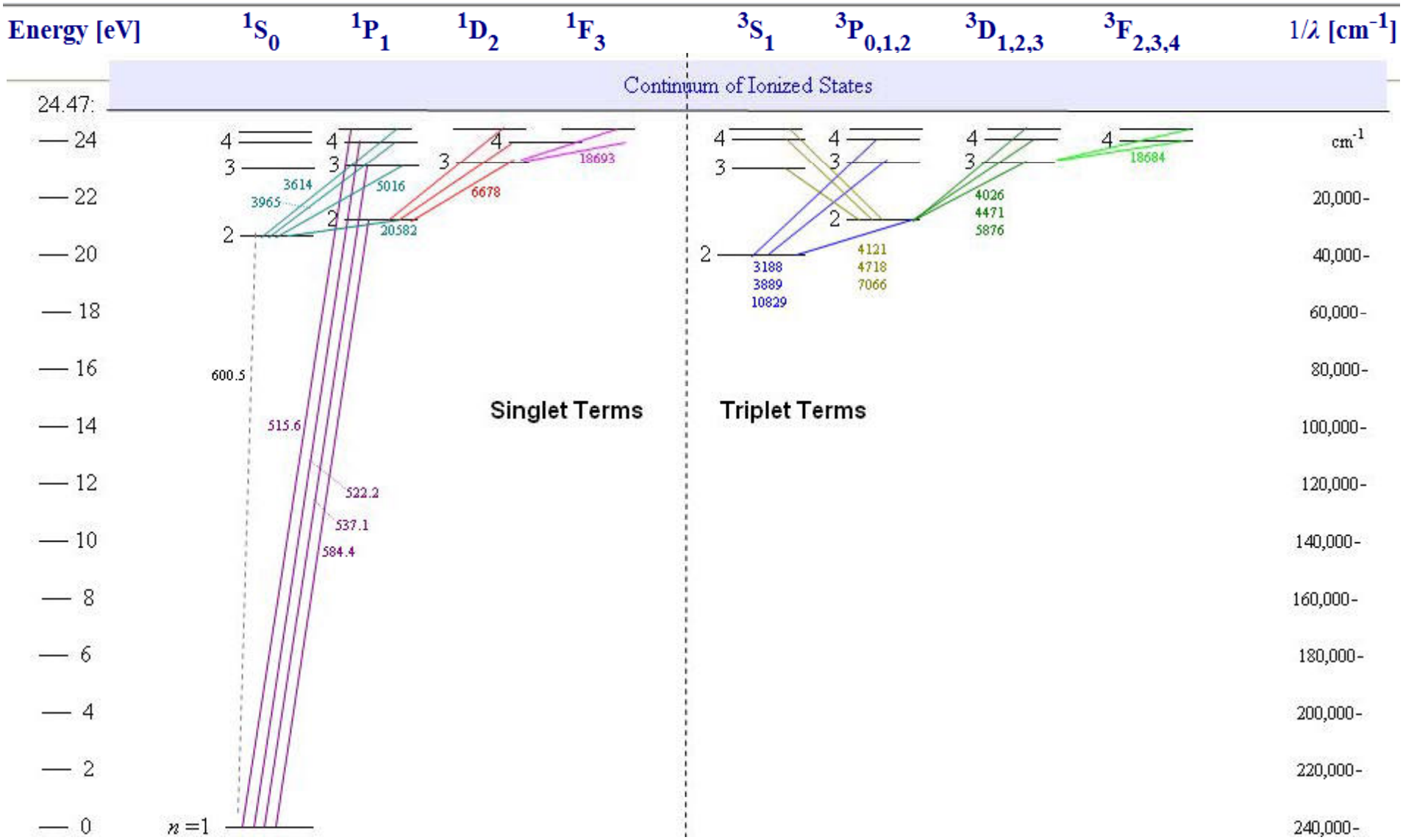
Deuterium and hydrogen α lines



Visible helium spectrum

From http://upload.wikimedia.org/wikipedia/commons/a/a4/Visible_spectrum_of_helium.jpg

Helium Grotrian diagram



From http://www.physics.byu.edu/faculty/christensen/Physics%20428/FTI/Helium%20Grotrian%20Diagram'.htm