Schedule

Today: Begin Lab 4
11/27: Finish Lab 4 - turn in homework #7
12/4: Exam Review - Lab 4 due
12/11: Final Exam?
12/17: Final Exam

Diffraction Grating

Maxima occur when \( \Delta = n\lambda \)

\[ a \sin \theta = n\lambda \]

Grating Eq.

Possible Diffraction envelope (depending on slit width)

Today's lab:
- Use known wavelength of Hg lamp to measure grating spacing \( a \)
- Use measured grating spacing to measure wavelength of Hg lamp A line.
Non-zero angle of incidence

\[ \Delta = a \sin \Theta \]

\[ \Delta_i = a \sin \Theta_i \]

Maxima when \( a (\sin \Theta_i + \sin \Theta) = n \lambda \)

0th, 1st, 2nd...

\( a \sin \Theta \)

\( a \sin \Theta_i \)

\( \Theta \) is measured from the normal to the grating.

But we only know roughly what angle corresponds to normal.

⇒ Measure angular position of 1st & -1st order peaks.

When \( a \Delta \Theta (n=1) = -a \Delta \Theta (n=-1) \), grating is perpendicular.

Suppose \( \sin \Theta_i = 0.67 \)

\[ a = 1.66 \text{ mm}, \lambda = 0.633 \text{ mm} \]

\[ \Theta = 51.0^\circ \]

\[ a \sin \Theta = 0.639 \mu \text{m} \]

-0.3898 μm, 0.0166 μm, 0.3698 μm
Suppose \( \alpha = 1.66 \mu m, \lambda = 0.633 \mu m, \) and \( \theta_1 = 0.01 \)

-2.98  -22.94°  -0.01  -0.57°  0.3698  21.70°  0.798  88.27°

\[ \Delta \theta \]

\[ \Delta \theta \]

Differ by \( \theta_1 \neq \theta \) due to \( \theta_1 \neq \theta \).

As read on spectrometer

\[ \Rightarrow \text{Adjust angle of grating until } +1 \text{ and } -1 \text{ peaks appear at equal angular distance from } \theta_1 \]
Hydrogen Energy Levels

\[ E_n = \frac{-13.6}{n^2} \text{ eV}, \quad n = 1, 2, 3, \ldots \]

\[ \Delta E = -13.6 \text{ eV} \left( \frac{1}{n^2} - \frac{1}{n'^2} \right) = \frac{\nu}{c} = \frac{\Delta \nu}{c} \]

Planck’s constant

\[ \frac{1}{\lambda} = \tilde{\nu} = \text{wavenumber} \]

\[ = \frac{\nu}{c} = \frac{\Delta E}{hc} = R \left( \frac{1}{n^2} - \frac{1}{n'^2} \right) \]

\[ hc = 1240 \text{ eV} \cdot \text{nm} \]

\[ R = \text{Rydberg constant}, \text{ units of cm}^{-1} \]

For transitions to \( n=1 \), \( \nu \) is UV (invisible) \( (\text{Lyman Series}) \)

Transition to \( n=2 \), \( \nu \) is visible \( (\text{Balmer Series}) \)

- Measure Balmer series wavelength,
- Guess which wavelength corresponds to which \( n' \)
- Extract Rydberg constant.
Laws

Three interactions between light and atoms:

- Stimulated absorption

\[ E_2 \rightarrow E_2 \quad \text{hv} = E_2 - E_1 \]

before \quad \text{after}

- Stimulated emission

\[ E_2 \rightarrow E_1 \quad \text{hv} \quad \text{same direction & phase} \]

before \quad \text{after}

- Spontaneous emission

\[ E_2 \rightarrow E_1 \quad \text{hv random phase} \]

before \quad \text{after}

Conventional light sources rely on spontaneous emission. Lasers use stimulated emission.
Lineshape Function

Real atomic energy levels have a small spread.\[ E_2 \rightarrow \frac{E_1}{E_0} \]

The probability that a photon will interact with the atom is called the lineshape function, \( g(\nu) \).

\[ g(\nu) \]

width \( \Delta \nu \)

Typically for an atom in vacuum:

\[ \frac{\Delta \nu}{\nu_0} \approx 10^{-8} \text{ to } 10^{-5} \]

\[ \int g(\nu) \, d\nu = 1 \text{ (normalized)} \]

\[ \Rightarrow \text{ Solve Here} \]

Rate Equation

box of atoms

incoming light

\[ I, \nu' \]

\[ N_1 \text{ in energy level } E_1 \]

\[ N_2 \text{ in energy level } E_2 \]

Rate of Stimulated Absorption per unit volume:

\[ R_{\text{stimabs}} = B_{12} \cdot g(\nu') \left( \frac{I}{c} \right) N_1 \]

\[ \text{proportionality constant (Einstein coeff.)} \]

Rate of Stimulated Emission per unit volume:

\[ R_{\text{stimemis}} = B_{21} \cdot g(\nu) \left( \frac{I}{c} \right) N_2 \]

\[ \text{Einstein coeff.} \]

Rate of Spontaneous Emission per unit volume:

\[ R_{\text{spontemis}} = A_{21} \cdot N_2 \text{ Einstein coeff.} \]
$A_{21}$, $B_{12}$, $B_{21}$ can be calculated with quantum mechanics. Einstein showed that in thermal equilibrium,

$$\frac{A_{21}}{B_{21}} = \frac{8\pi \hbar v^3}{c^3} \quad \text{and} \quad B_{21} = B_{12}$$

But these ratios must also be true out of thermal equilibrium, because $A_{21}$, $B_{12}$, $B_{21}$ are fundamental properties of the atoms.