Quick Intro to Spectroscopy

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Space Odyssey Training
Electromagnetic Radiation

Image Credit: Lookang
Electromagnetic Radiation

Light is both wave-like and particle-like!

Plane Waves vs. Wave Packets

\[ \Psi(x, t) = A \exp\left[ i (kx - \omega t) \right] \]

\[ \Psi(x, t) = \sum_n A_n \exp\left[ i (k_n x - \omega_n t) \right] \]
Electromagnetic Radiation: Photons

Energy absorbed and emitted by matter in discrete units or photons with energy

\[ E = h \times \nu \]

with frequency \( \nu \) in \([\text{sec}^{-1}]\) or [Hertz],
\[ h = 6.626 \times 10^{-34} \text{ Joule} \times \text{sec} \]
Blackbody Radiation

$T = 1000-1200 \degree C$ or $1830-2190 \degree F$

$T = 36 \degree C$ or $97 \degree F$

$T = 5500 \degree C$ or $10,000 \degree F$

Image Credits: IPAC, Hawaii Volcano Observatory, NASA
Blackbody Radiation

Diagram showing the emitted energy vs. wavelength for different temperatures (5000 K, 4000 K, 3000 K). The graph illustrates how the peak emission shifts to shorter wavelengths as the temperature decreases.
Blackbody Radiation Interactives

https://phet.colorado.edu/sims/blackbody-spectrum/blackbody-spectrum_en.html

https://highered.mheducation.com/olcweb/cgi/pluginpop.cgi?it=swf::800::600::/sites/dl/free/0072482621/220727/Blackbody_Nav.swf::Blackbody%20Radiation%20Interactive
Bohr Atom: Hydrogen
Bohr Atom: Hydrogen

<table>
<thead>
<tr>
<th>n</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>∞</td>
<td>E = 0</td>
</tr>
<tr>
<td>4</td>
<td>E = -0.85 eV</td>
</tr>
<tr>
<td>3</td>
<td>E = -1.51 eV</td>
</tr>
<tr>
<td>2</td>
<td>E = -3.40 eV</td>
</tr>
<tr>
<td>1</td>
<td>E = -13.6 eV</td>
</tr>
</tbody>
</table>
Bohr Atom: Absorption of Photon

\begin{align*}
n&= \infty \quad \quad E = 0 \\
n&= 4 \quad \quad E = -0.85 \text{ eV} \\
n&= 3 \quad \quad E = -1.51 \text{ eV} \\
n&= 2 \quad \quad E = -3.40 \text{ eV} \\
n&= 1 \quad \quad E = -13.6 \text{ eV}
\end{align*}
Bohr Atom: Emission of Photon

\begin{align*}
{n=\infty} & : E = 0 \\
{n=4} & : E = -0.85 \text{ eV} \\
{n=3} & : E = -1.51 \text{ eV} \\
{n=2} & : E = -3.40 \text{ eV} \\
{n=1} & : E = -13.6 \text{ eV}
\end{align*}
Lyman Series of Lines

Limit: 911.267 Å
Ly $\gamma$: 972.02 Å
Ly $\beta$: 1025.18 Å
Lyman$\alpha$: 1215.67 Å
Balmer Series

\[
\begin{align*}
\text{n=\infty} & \quad \text{---} \quad E = 0 \\
\text{n=4} & \quad \text{---} \quad E = -0.85 \text{ eV} \\
\text{n=3} & \quad \text{---} \quad E = -1.51 \text{ eV} \\
\text{n=2} & \quad \text{---} \quad E = -3.40 \text{ eV} \\
\text{n=1} & \quad \text{---} \quad E = -13.6 \text{ eV}
\end{align*}
\]
Bohr Atom: Hydrogen
Hydrogen Wave Function

Probability density plots.

\[ \psi_{n\ell m}(r, \theta, \varphi) = \left( \frac{2}{n\alpha_0} \right)^3 \frac{(n - l - 1)!}{2n[(n + l)!]} e^{-2n/\alpha_0} L_{n-l-1}^2(\rho) \cdot Y_{\ell m}(\theta, \varphi) \]
Kirchhoff’s Laws

- Hot opaque object emits blackbody spectrum
- Cooler gas creates absorption spectrum
- Hot diffuse gas produces line emission spectrum

Image Credit: Penn State Astronomy & Astrophysics
Solar Spectrum

Image Credit: Wabash Instrument Corporation
Isaac Newton believed light to consist of particles.
Wave Experiments

“Water Waves – Diffraction” https://www.youtube.com/watch?v=loyV2dljw18
Wave Interference

Constructive interference

Destructive interference

Image Credit: www.virtualmuseum.ca
Wave Experiments

“Water Waves – Interference” https://www.youtube.com/watch?v=VUUGCtFzFX8
Electromagnetic Radiation Waves

“The Original Double Slit Experiment,” https://www.youtube.com/watch?v=Iuv6hY6zsd0
Diffraction Gratings

Path difference: $d (\sin \theta_i \pm \sin \theta_m)$

Image Credit: Vigneshdm 1990
Image Credit: http://hyperphysics.phy-astr.gsu.edu
Diffraction Glasses

GloFX Ultimate Diffraction Glasses - 3D Prism Effect EDM Rainbow Kaleidoscope Style Rave Sunglasses

Price: $9.95 prime
FREE Shipping on orders over $25—or get FREE Two-Day Shipping with Amazon Prime
FREE Returns

Color: Black

In Stock.
Flashlight

Laser

Incandescent

CFL

LED

Cosmic Microwave Background Spectrum
Atmospheric Transparency

Gamma rays, X-rays and ultraviolet light blocked by the upper atmosphere (best observed from space).

Visible light observable from Earth, with some atmospheric distortion.

Most of the infrared spectrum absorbed by atmospheric gases (best observed from space).

Radio waves observable from Earth.

Long-wavelength radio waves blocked.

Image Credit: NASA
Filter Passbands

UBVRI Photometry Passbands

Image Credit: Australia Telescope National Facility
Hot Star and Cool Star Spectra and B & V Bands

Image Credit: Australia Telescope National Facility
B & V Bands for Cool Star

Visible Light Portion of Blackbody Radiation
3,000 K Star

Colour Index = B - V
B - V = positive value

star appears red

V intensity
550 nm

B intensity
440 nm

Energy Density (Watts/sq m)

Wavelength (m)

Image Credit: Australia Telescope National Facility
B & V Bands for Hot Star

Image Credit: Australia Telescope National Facility
Electron Diffraction

Image Credit: Tonomura
Electron Diffraction

Image Credit: Tonomura