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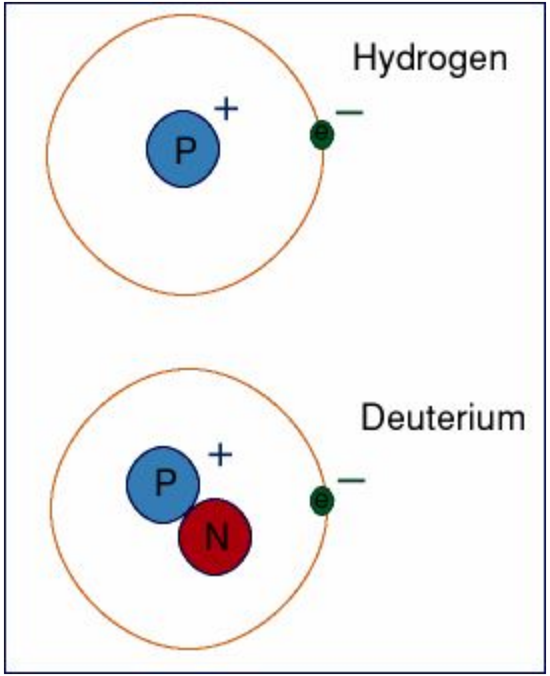
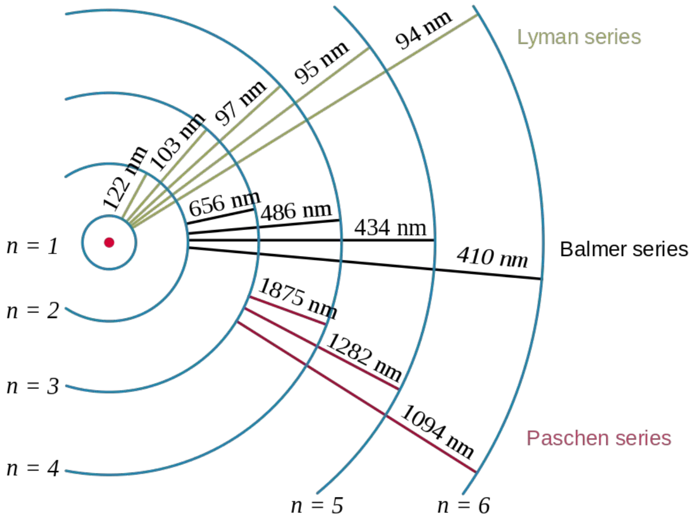
H2D2 Spectroscopy



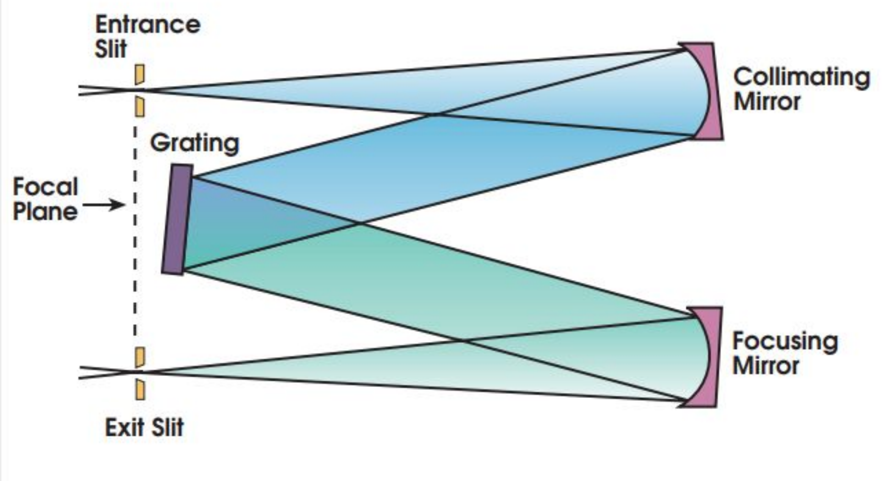
Main Idea

- Electron relaxation results in photons of set energy.
- Balmer Series is the spectrum of visible light photons released due to relaxation to the first excited state.
- Nuclear mass affects the wavelengths of released photons.



Instrumentation and Data Collection

- Light enters monochromator through a narrow slit where it is focused by two mirrors and a diffraction grating.
- Results in only a narrow part of the spectrum being measured at a time.
- Took weather data in order to find the index of refraction for each wavelengths being measured.



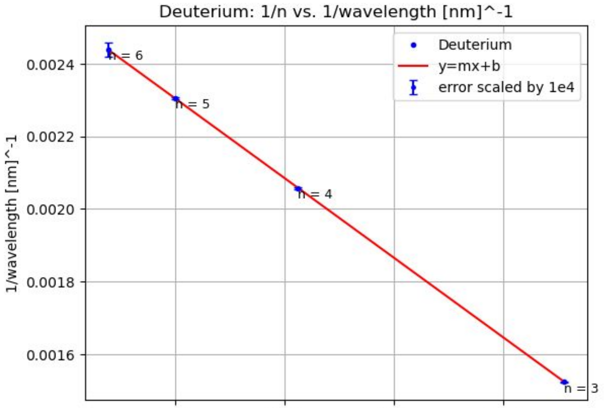
Data Analysis

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n_i^2}\right)$$

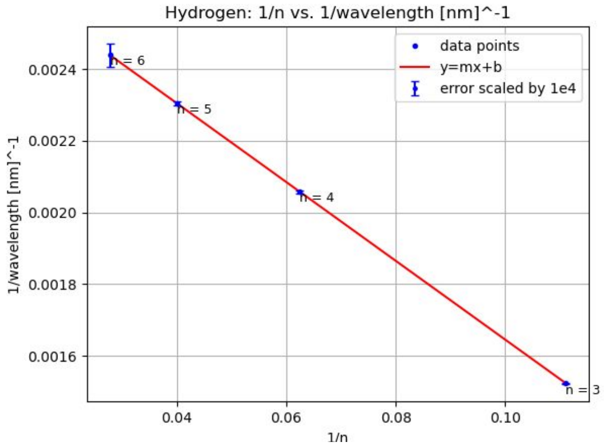
$$y = \frac{1}{\lambda} \qquad x = \frac{1}{n_i^2}$$

$$y = R\left(\frac{1}{2^2} - x\right) \rightarrow y = \frac{R}{4} - Rx$$

- Used linearized version of the Rydberg formula in order to find the Rydberg constant for each nuclei.
- Used each Rydberg constant to find the reduced electron mass ratio for each atom.



y = (-0.01097763+/-0.00000087)x + (0.00274380+/-0.00000006)

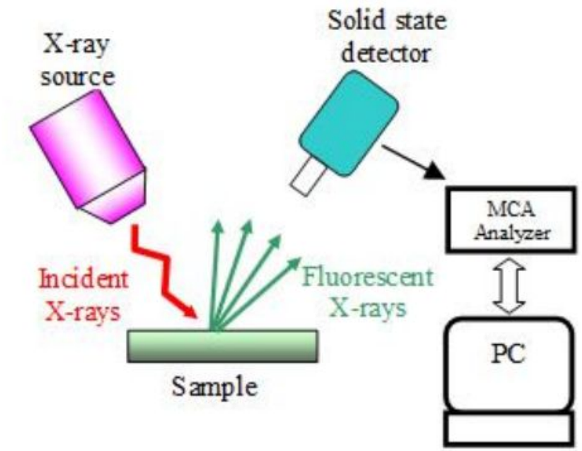


y = (-0.01097462+/-0.00000100)x + (0.00274306+/-0.00000007)

Spectroscopy in Art Analysis

- The fact that excited photons re-emit photons of specific energies can help to determine the materials used in art.

- Since the mass of the nucleus changes the wavelength of there relaxation photons, wavelength measurements can be used to determine the nuclei in the material being analysed.



$$E_x = (Z-1)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right)$$

for S: $Z = 16$; $E_x = (15)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 2.29\,[eV]$

for Ca: $Z = 20$; $E_x = (19)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 3.68\,[eV]$

for Ti: $Z = 22$; $E_x = (21)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 4.50\,[eV]$

for Fe: $Z = 26$; $E_x = (25)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 6.37\,[eV]$

for Zn: $Z = 30$; $E_x = (29)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 8.58\,[eV]$

Antimony white	Sb_2O_3
Lithopone	$ZnO + BaSO_4$
Permanent white	$BaSO_4$
Titanium white	TiO_2
White lead	$2PbCO_3 \cdot Pb(OH)_2$
Zinc white	ZnO
Zirconium oxide	ZrO_2
Chalk	$CaCO_3$
Gypsum	$CaSO_4 \cdot 2H_2O$

Yellow pigments

Auripigmentum	As_2S_3
Cadmium yellow	CdS
Chrome yellow	$2PbSO_4 \cdot PbCrO_4$
Cobalt yellow	$K_3[Co(NO_2)_6] \cdot 1.5H_2O$
Lead–tin yellow	$Pb_2SnO_4/PbSn_2SiO_7$
Massicot	PbO
Naples yellow	$Pb(SbO_3)_2/Pb_3(SbO_4)_2$
Strontium yellow	$SrCrO_4$
Titanium yellow	$NiO \cdot Sb_2O_3 \cdot 20TiO_2$
Yellow ochre	$Fe_2O_3 \cdot nH_2O$ (20–70%)
Zinc yellow	$K_2O \cdot 4ZnO \cdot 4CrO_3 \cdot 3H_2O$

Red pigments

Cadmium red	$CdS + CdSe$
Cadmium vermilion	$CdS + HgS$
Chrome red	$PbO \cdot PbCrO_4$
Molybdate red	$7PbCrO_4 \cdot 2PbSO_4 \cdot PbMoO_4$
Realgar	As_2S_3
Red lead	Pb_3O_4
Red ochre	Fe_2O_3 (up to 90%)
Vermilion	HgS

Basic copper sulfate	$Cu_x(SO_4)_y(OH)_z$
Chromium oxide	Cr_2O_3
Chrysocolla	$CuSiO_3 \cdot nH_2O$
Cobalt green	$CoO \cdot 5ZnO$
Emerald green	$Cu(CH_3COO)_2 \cdot 3Cu(As$
Guignent green	$Cr_2O_3 \cdot nH_2O + H_3BO_3$
Malachite	$CuCO_3 \cdot Cu(OH)_2$
Verdigris	$Cu(CH_3COO)_2 \cdot nCu(O$

Blue pigments

Azurite	$2CuCO_3 \cdot Cu(OH)_2$
Cerulean blue	$CoO \cdot nSnO_2$
Cobalt blue	$CoO \cdot Al_2O_3$
Cobalt violet	$Co_3(PO_4)_2$
Egyptian blue	$CaO \cdot CuO \cdot 4SiO_2$
Manganese blue	$BaSO_4 \cdot Ba_3(MnO_4)_2$
Prussian blue	$Fe_4[Fe(CN)_6]_3$
Smalt	Co-glass ($K_2O + SiO_2$
Ultramarine	$Na_{8-10}Al_6Si_6O_{24}S_{2-4}$

Black pigments

Antimony black	Sb_2O_3
Black iron oxide	$FeO \cdot Fe_2O_3$
Carbon or charcoal black	C (95%)
Cobalt black	CoO
Ivory black	$C + Ca_3(PO_4)_2$
Manganese oxide	$Mno + Mn_2O_3$

References

Wiescher, Michael, "Radioactivity: Lecture 25, Radioactivity and Art Analysis". From "Radioactivity and its implications for environment and society [Fall 2017]" class. University of Notre Dame, Institute for Structure and Nuclear Astrophysics, URL: https://isnap.nd.edu/assets/258293/radioactivity_lecture_25.pdf

Jean-Luc Domanchin and John R. Gilchrist, “Size and Spectrum”, URL: https://www.horiba.com/fileadmin/uploads/Scientific/Documents/OSD/size_spectrum.pdf