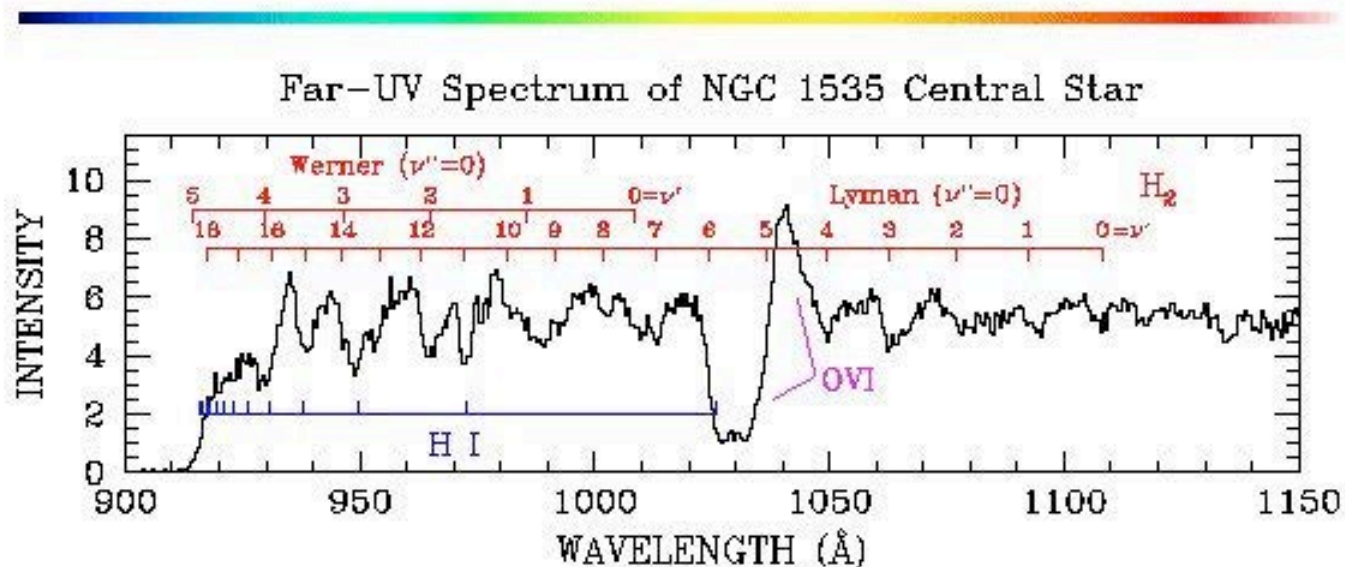


Spectroscopy: The Study of Squiggly Lines

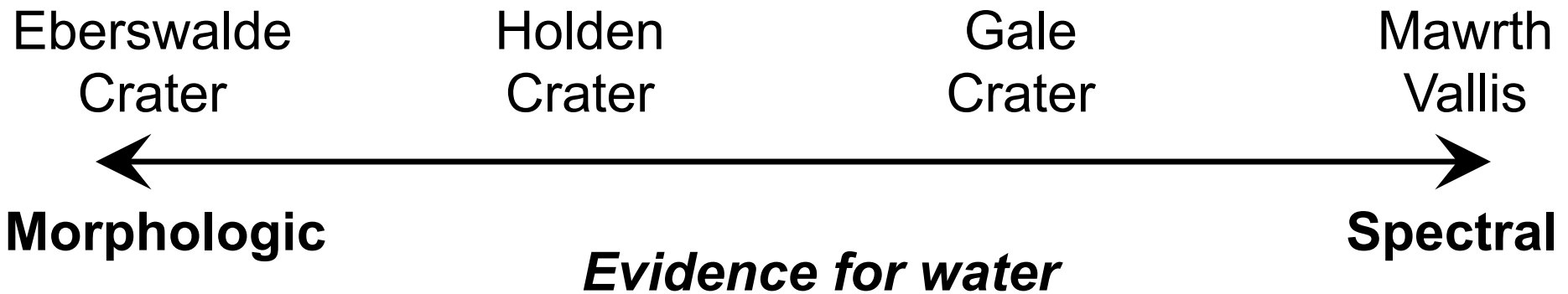
[\[Astronomical Distances\]](#) [\[Basics of Light\]](#) [\[Tools for Light Analysis\]](#)
[\[Measuring Light\]](#) [\[Electromagnetic Spectrum\]](#) [\[Fun with Units\]](#)
[\[Atmospheric Transmission\]](#) [\[Space Links\]](#)

What are Those Squiggly Lines?

Using Light to Learn About the Universe



Spectroscopy in Curiosity's site selection



Interaction of Radiant Energy and Matter

What causes absorption features in spectra?

- 1) Rotational absorption (gases)**
- 2) Electronic absorption**
- 3) Vibrational absorption**

Rotational Processes

Photons striking *free* molecules can cause them to rotate. The rotational states are quantized, so there are discrete photon energies that, when absorbed, cause the molecules to spin.

Rotational interactions are low-energy interactions and the absorption features are at long infrared wavelengths.

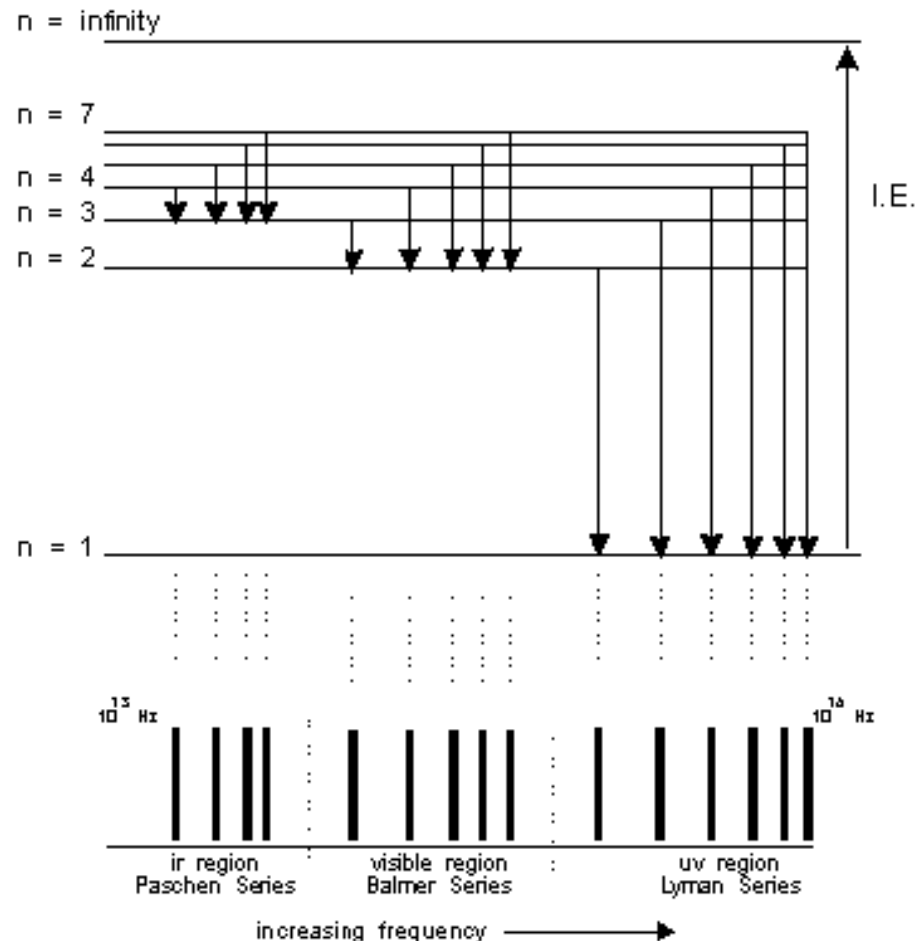
Not important in remote sensing of solid materials

Electronic Processes

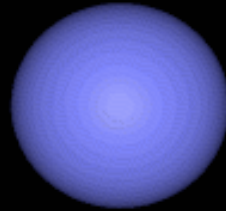
Isolated atoms and ions have discrete energy states. Absorption of photons of a specific wavelength causes a change from one energy state to a higher one.

In solids, four types:

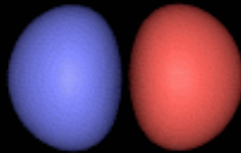
- Crystal Field Effects
- Charge Transfer Absorptions
- Conduction Bands
- Color Centers



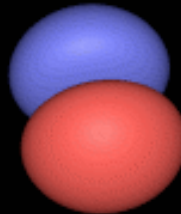
Electron Orbits



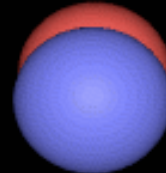
s



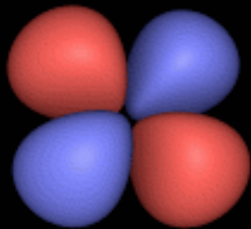
p_x



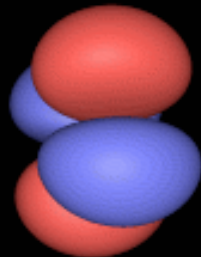
p_y



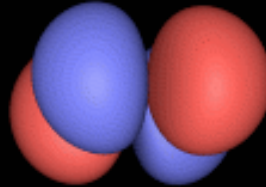
p_z



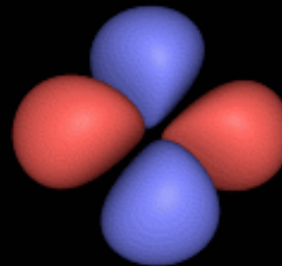
d_{xy}



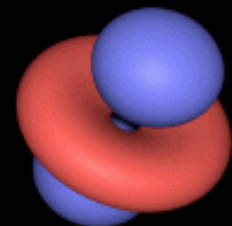
d_{xz}



d_{yz}



d_{x² - y²}



d_{z²}

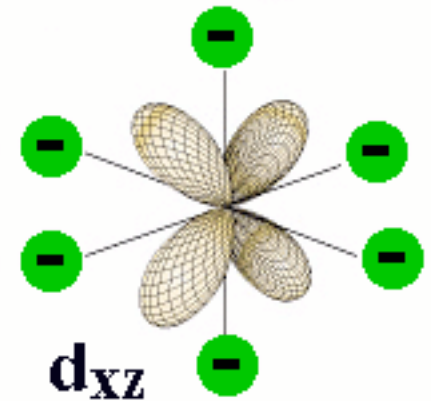
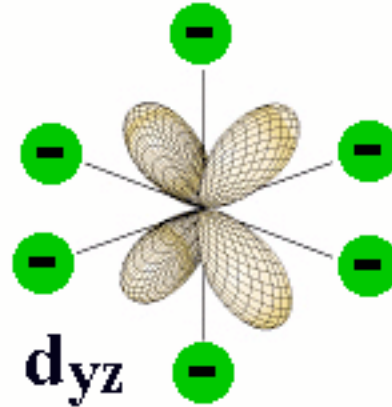
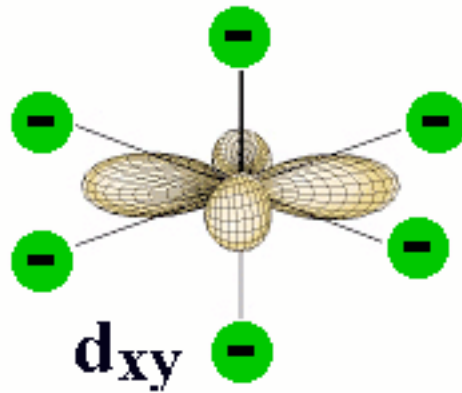
Electronic Processes

Crystal Field Effects

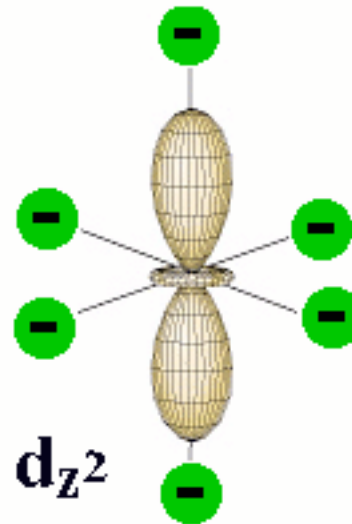
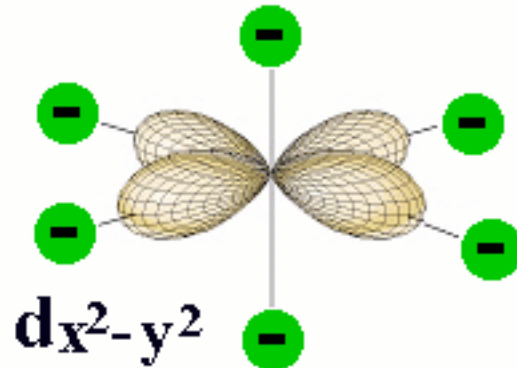
The electronic energy levels of an isolated ion are usually split and displaced when located in a solid. Unfilled d orbitals are split by interaction with surrounding ions and assume new energy values. These new energy values (transitions between them and consequently their spectra) are primarily determined by the valence state of the ion (Fe^{2+} , Fe^{3+}), coordination number, and site symmetry.

Energy Level Splitting in Solids: Part 1

**Lower
Energy
Levels**



**Higher
Energy
Levels**



In a free atom these have equal energy, but not in a crystal...

Unfilled *d* orbitals: the transition metals

Periodic Table of the Elements

1 1 H Hydrogen 1.00784	2 4 He Helium 4.002602											13 5 B Boron 10.811	14 6 C Carbon 12.0107	15 7 N Nitrogen 14.00674	16 8 O Oxygen 15.9994	17 9 F Fluorine 18.9984032	18 10 Ne Neon 20.1797
3 3 Li Lithium 6.941	4 4 Be Beryllium 9.012182											13 13 Al Aluminum 26.981538	14 14 Si Silicon 28.0855	15 15 P Phosphorus 30.973761	16 16 S Sulfur 32.066	17 17 Cl Chlorine 35.453	18 18 Ar Argon 39.948
11 3 Na Sodium 22.989770	12 2 Mg Magnesium 24.3050	3 21 Sc Scandium 44.955910	4 22 Ti Titanium 47.867	5 23 V Vanadium 50.9415	6 24 Cr Chromium 51.9961	7 25 Mn Manganese 54.938049	8 26 Fe Iron 55.845	9 27 Co Cobalt 58.933200	10 28 Ni Nickel 58.6934	11 29 Cu Copper 63.546	12 30 Zn Zinc 65.409	13 31 Ga Gallium 69.723	14 32 Ge Germanium 72.64	15 33 As Arsenic 74.92160	16 34 Se Selenium 78.96	17 35 Br Bromine 79.904	18 36 Kr Krypton 83.798
19 4 K Potassium 39.0983	20 2 Ca Calcium 40.078	39 39 Y Yttrium 88.90585	40 40 Zr Zirconium 91.224	41 41 Nb Niobium 92.90638	42 42 Mo Molybdenum 95.94	43 43 Tc Technetium (98)	44 44 Ru Ruthenium 101.07	45 45 Rh Rhodium 102.90550	46 46 Pd Palladium 106.42	47 47 Ag Silver 107.8682	48 48 Cd Cadmium 112.411	49 49 In Indium 114.818	50 50 Sn Tin 118.710	51 51 Sb Antimony 121.760	52 52 Te Tellurium 127.60	53 53 I Iodine 126.90447	54 54 Xe Xenon 131.293
37 5 Rb Rubidium 85.4678	38 2 Sr Strontium 87.62	57 to 71										81 81 Tl Thallium 204.3853	82 82 Pb Lead 207.2	83 83 Bi Bismuth 208.98038	84 84 Po Polonium (209)	85 85 At Astatine (210)	86 86 Rn Radon (222)
55 6 Cs Cesium 132.90545	56 2 Ba Barium 137.327	89 to 103										113 113 Uut Ununtrium (284)	114 114 Uuq Ununquadium (288)	115 115 Uup Ununpentium (288)	116 116 Uuh Ununhexium (292)	117 117 Uus Ununseptium	118 118 Uuo Ununoctium
87 7 Fr Francium (223)	88 2 Ra Radium (226)											109 109 Mt Meitnerium (268)	110 110 Ds Darmstadtium (271)	111 111 Rg Roentgenium (272)	112 112 Uub Ununbium (285)		

Atomic masses in parentheses are those of the most stable or common isotope.

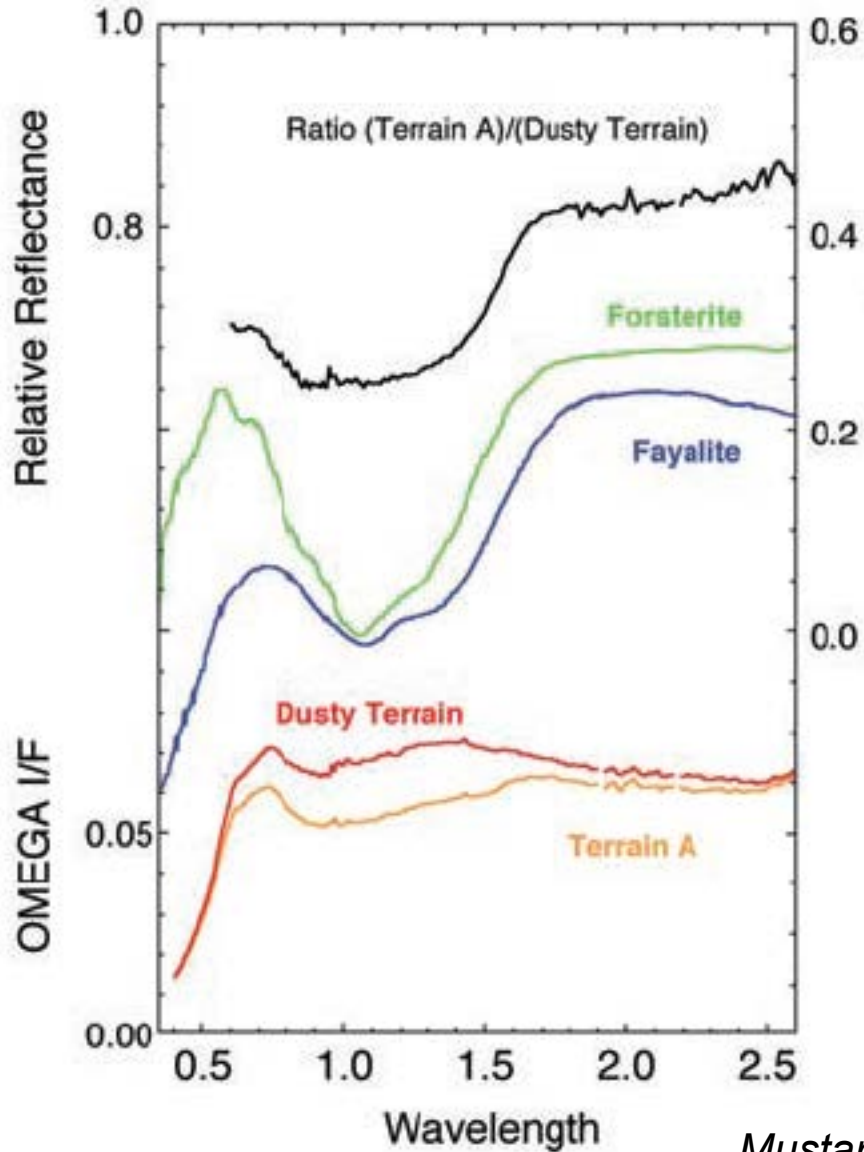
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Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

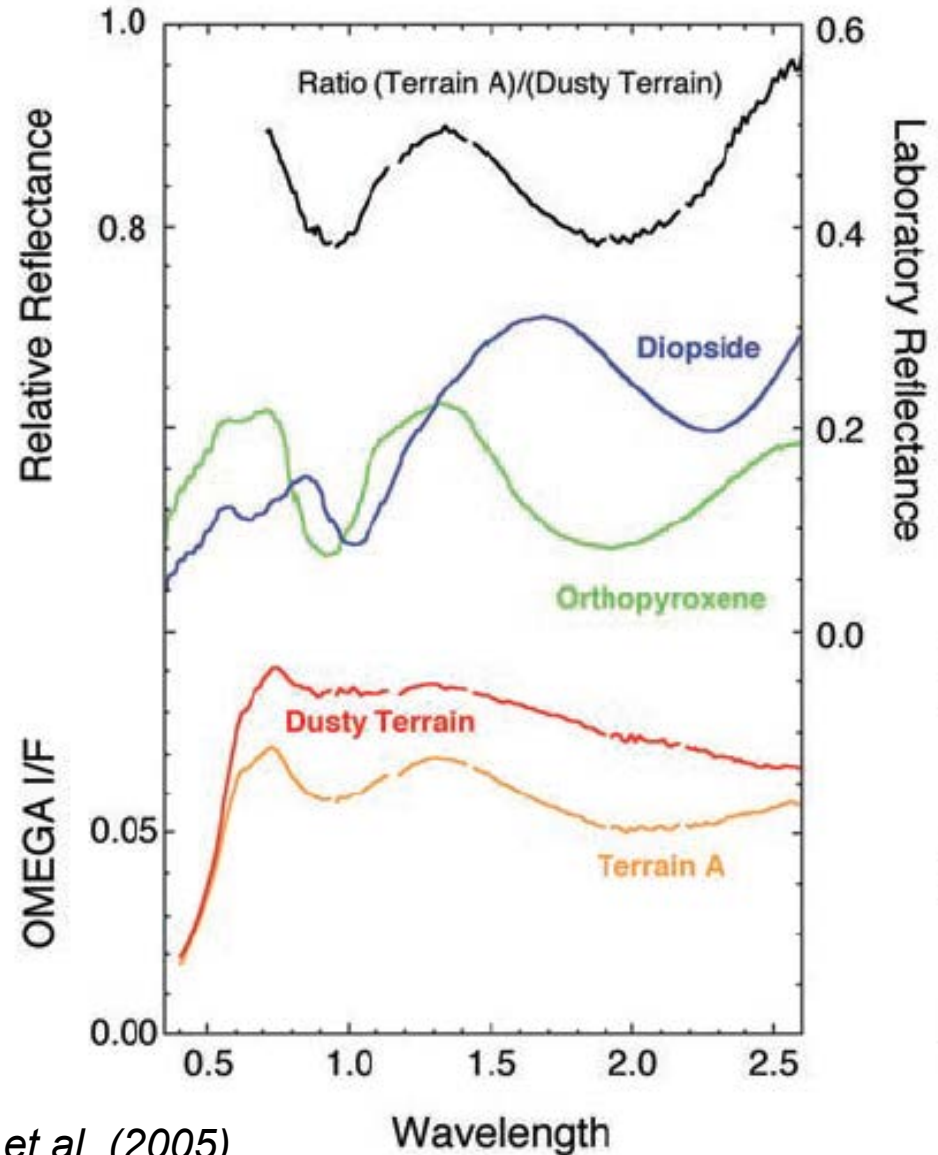
57 2 La Lanthanum 138.9055	58 2 Ce Cerium 140.116	59 2 Pr Praseodymium 140.90765	60 2 Nd Neodymium 144.24	61 2 Pm Promethium (145)	62 2 Sm Samarium 150.36	63 2 Eu Europium 151.964	64 2 Gd Gadolinium 157.25	65 2 Tb Terbium 158.92534	66 2 Dy Dysprosium 162.500	67 2 Ho Holmium 164.93032	68 2 Er Erbium 167.259	69 2 Tm Thulium 168.93421	70 2 Yb Ytterbium 173.04	71 2 Lu Lutetium 174.967
89 2 Ac Actinium (227)	90 2 Th Thorium 232.0381	91 2 Pa Protactinium 231.03688	92 2 U Uranium 238.02891	93 2 Np Neptunium (237)	94 2 Pu Plutonium (244)	95 2 Am Americium (243)	96 2 Cm Curium (247)	97 2 Bk Berkelium (247)	98 2 Cf Californium (251)	99 2 Es Einsteinium (252)	100 2 Fm Fermium (257)	101 2 Md Mendelevium (258)	102 2 No Nobelium (259)	103 2 Lr Lawrencium (262)

Iron is the most geologically abundant transition metal

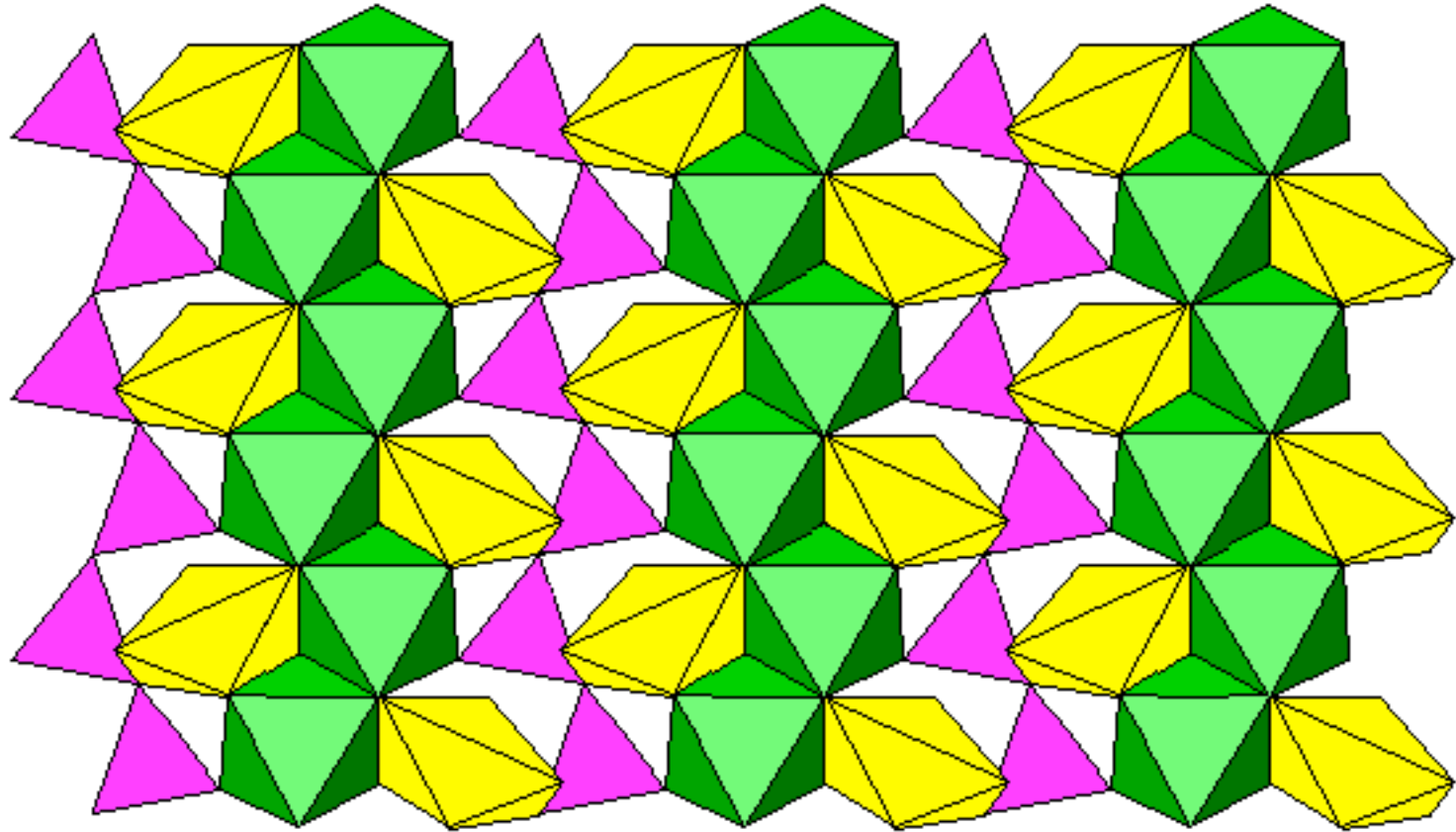
Fe electronic transitions in olivine, pyroxene



Mustard et al. (2005)



Energy Level Splitting in Solids: Part 2



Distortion of some “sites” in a crystal → further energy splitting
→ *diagnostic of mineralogy*

Spectroscopy: linking meteorites to asteroids

