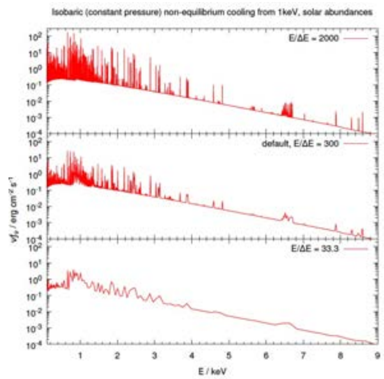
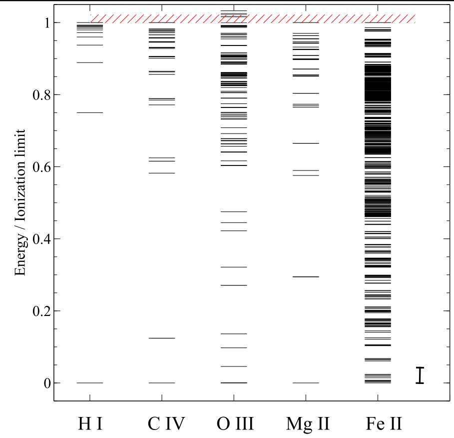
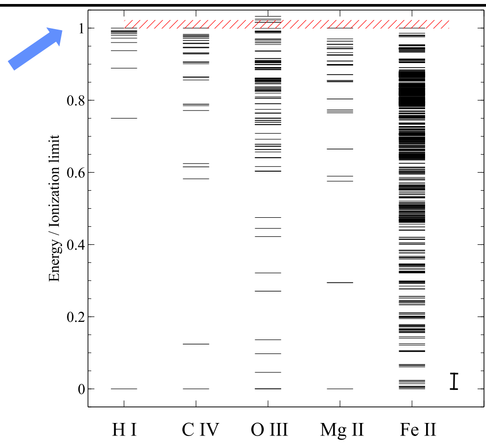
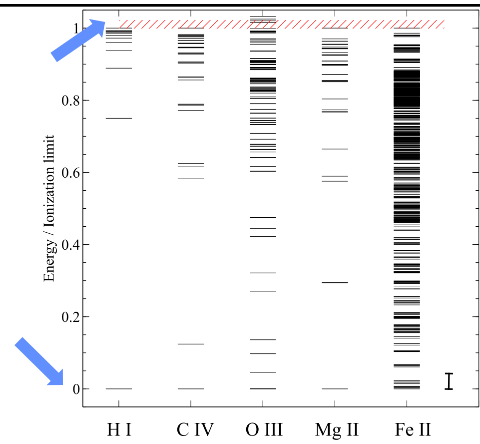
- **How to make sense of all these lines**









Peter's atomic line list

- http://www.pa.uky.edu/~peter/atomic/
- http://www.pa.uky.edu/~peter/newpage/
  - Beta version with new features
- **Search wavelength range to find what lines are present**

NIST

- http://www.nist.gov/pml/data/asd.cfm

2014 Cloudy workshop

NIST Atomic Spectra Database Levels Form

Best viewed with the latest versions of Web browsers and Jav

This form provides access to NIST critically evaluated data on atomic energy levels.

Spectrum: o iii e.g., Fe I

Default Values | Retrieve Data

Level Units: cm-1

Format output: HTML (formatted)

Display output: in its entirety

Page size: 15

Term ordered (•) term energy ☐

Energy ordered ( )

Level information: ☑ Principal configuration

☑ Principal term

☑ Level ☑ J

☑ Lande-g

Extended Search: Set Additional Criteria for all levels sear

Primary data sources		Query NIST Bibliographic Databases for O III (new window)
Energy Levels:	Moore 1993	O III Energy Levels
Lines:	Reader et al. 1980	O III Line Wavelengths and Classification
Transition Probabilities:	Wiese et al. 1996	O III Transition Probabilities

Ritz Wavelength Air (Å)	Rel. Int.	A_{ki} (s^{-1})	Acc.	E_i (cm^{-1})		E_k (cm^{-1})	Lower Level Conf., Term, J			Upper Level Conf., Term, J			Type	TP Ref.	Line Ref.
4 958.911		6.21e-03	B	113.178	-	20 273.27	$2s^22p^2$	^3P	1	$2s^22p^2$	^1D	2	M1	T4010,T4899,T4026	
4 958.911		4.57e-06	C+	113.178	-	20 273.27	$2s^22p^2$	^3P	1	$2s^22p^2$	^1D	2	E2	T4899	
5 006.843		1.81e-02	B	306.174	-	20 273.27	$2s^22p^2$	^3P	2	$2s^22p^2$	^1D	2	M1	T4010,T4899,T4026	

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arXiv.org > physics > arXiv:1905.09276

Search... Help | Ad

Physics > History and Philosophy of Physics

Einstein's biggest mistake?

Gary J. Ferland

(Submitted on 15 Apr 2019)

What, if any, was Einstein's biggest mistake, the one most affecting our physics today? There is a perhaps apocryphal story, recounted by George Gamow, that he counted his cosmological constant as his biggest blunder. We now know his hypothesized cosmological constant to be correct. His lifelong rejection of quantum mechanics, an interesting side-story in the evolution of 20th-century physics, is a candidate. None of these introduced difficulties in how our physics is done today. It can be argued that his biggest actual mistake, one that affects many subfields of physics and chemistry and bewilders students today, occurred in his naming of his A and B coefficients.

Comments: Observatory in press

Subjects: History and Philosophy of Physics (physics.hist-ph)

Cite as: arXiv:1905.09276 [physics.hist-ph]

(or arXiv:1905.09276v1 [physics.hist-ph] for this version)

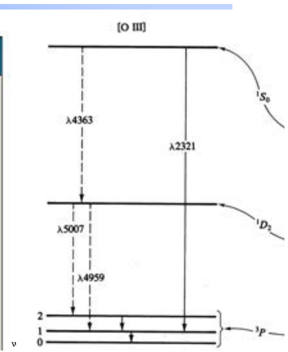
Submission history

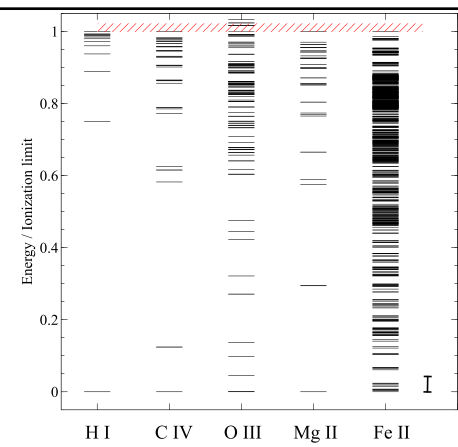
From: Gary J. Ferland [view email]

[v1] Mon, 15 Apr 2019 13:38:34 UTC (3 KB)

O III

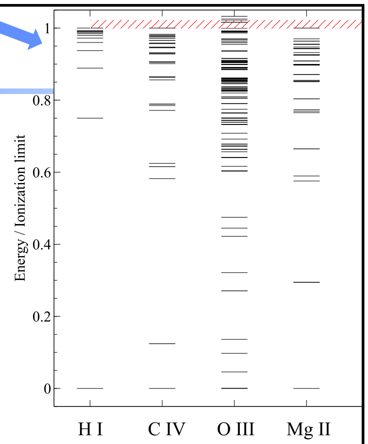
Configuration	Term	J	Level (cm^{-1})
$2s^22p^2$	^3P	0	0
		1	113.178
		2	306.174
$2s^22p^2$	^1D	2	20 273.27
$2s^22p^2$	^1S	0	43 185.74
$2s2p^3$	$^5S°$	2	60 324.79
$2s2p^3$	$^3D°$	3	120 025.2
		2	120 053.4
		1	120 058.2



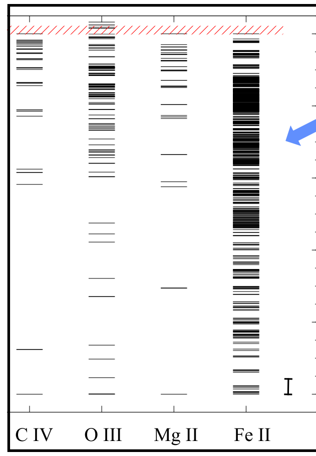


Two cases

- One and two electron systems
- Levels are closer to the continuum above than the ground state below



Two cases



- Many electron systems
- Levels have range of energies
- Many are close to the ground state below

Two types of lines

- **Recombination lines AGN3 sec 4.2**
  - e + p radiative recombination
  - Rate coefficient $q \sim 10^{-13}$ cm^3 s^{-1}
  - Mainly H, He in optical/IR, 1 and 2 electron O, C, Fe in the X-ray
  - Lines do not cool the gas since no kinetic energy is removed
- **Collisionally excited lines AGN3 3.5**
  - Inelastic e + ion collision
  - Lines cool the gas
  - $q \sim 10^{-9}$ cm^3 s^{-1}
  - Heavy elements

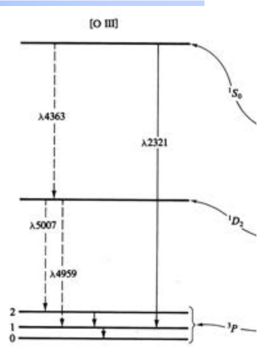
Selection rules for transitions

- **AGN3**
- **Appendix 4 Nebular quantum mechanics**
- **Appendix 6 Molecular quantum**

- **O III obeys all selection rules, A~10^6 - 10^8 s^{-1}**
- **O III] violates a minor one A~100 s^{-1}**
- **[O III] violates rules A $\leq$ 1 s^{-1}**

O III

Configuration	Term	J	Level (cm^{-1})
$2s^2 2p^2$	^3P	0	0
		1	113.178
		2	306.174
$2s^2 2p^2$	^1D	2	20 273.27
$2s^2 2p^2$	^1S	0	43 185.74
$2s2p^3$	$^5S°$	2	60 324.79
$2s2p^3$	$^3D°$	3	120 025.2
		2	120 053.4
		1	120 058.2



Species vs spectra

- **H^0, C^{3+}, O^{2+}, H_2, CO are baryons**
- **H I, C IV, O III, H_2, and CO are the spectra they emit / absorb**
- **O III is a permitted line produced by O^{2+}, while [O III] is a forbidden line**
- **C III] is a semi-forbidden line, often an intercombination line**

Species vs spectra

- **H I Lyα *emission* can be produced by**
  - Recombination of H^+
  - Impact excitation of H^0
- **H I absorption can only be produced by H^0**
- **H I is not the same as H^0**
  - Ambiguous for emission lines

Baryons and spectra

- **Hazy 1 Section 2.5**
- **SpeciesLabels.txt in docs**
- **Molecules are not ambiguous**
  - H2
  - CO
  - O2
  - H2+
  - C2+
  - Their spectra have the same notation as the baryon

Baryons and spectra

- **Atomic spectra use number of spectra**
  - H 1. C 4
- **The baryon**
  - "H", "He+", "C+2" (C2+ is C_2^+ in our notation)

2.5 "Species", how we specify atoms, ions, and molecules, and their spectra

2.5.1 Overview

CLOUDY simulates gas ranging from fully ionized to molecular. Nomenclature varies considerably between chemical, atomic, and plasma physics. We adopted a nomenclature that tries to find a middle ground between these different fields.

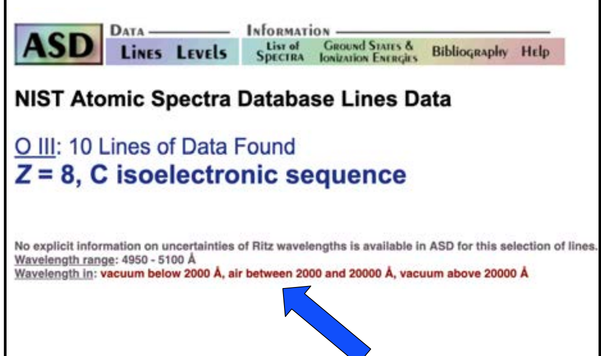
We refer to a particular atom, ion, or molecule as a "species". A species is a baryon. Examples are CO, H_2, H^+, and Fe^{22+}. Species are treated using a common approach, as much as possible.

Lines in the main output

- **Print lines column**
- **Print lines sort wavelength**
- **Print lines faint**

Finding lines in Cloudy

- **A line is identified by a spectral label & wavelength**
- **docs/LineLabels.txt has label, wavelength, comment about line**
  - Generated with command "Save line labels"
- **Pick lines from this file**



Air vs vacuum wavelengths

- The rule in atomic physics has been to use vacuum wavelengths for λ < 2000Å and air for λ > 2000Å
- SDSS has used vacuum for all wavelengths
- Today's papers use a mix of both
- Vacuum is probably the future
- Print line vacuum
  - But you need to change your wavelengths

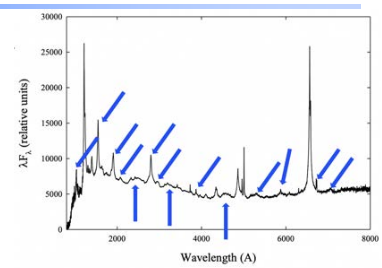
Some familiar lines

Species	λ(air)	λ(vacuum)
H 1	1215.67A	1215.67A
O 2	3726.03A	3727.09A
O 2	3728.81A	3729.88A
O. 3	4363.21A	4364.44A
H 1	4861.33A	4862.69A
O 3	5006.84A	5008.24A
H. 1	6562.81A	6564.62A

Other database reporting options

- See C17 review article, section 2
- Database print

Line blends (actually multiplets)



- Blnd 3727
- Blnd 2798
- Blnd 1549
- Two or more lines that appear as a single line in most spectra

Luminosity, relative intensity

- Intensity or luminosity of line
  - depending on case
- Intensity relative to normalization line, default Hβ
  - Change with *normalize* command

```
O  3 88.3323m   -5.577    1.5126
O  3 51.8004m   -5.106    4.4704
O  3 4931.23A   -8.339    0.0026
O  3 4958.91A   -4.876    7.5973
O  3 5006.84A   -4.401   22.6702
O  3 2320.95A   -7.193    0.0366
O  3 4363.21A   -6.593    0.1456
O  3 1660.81A   -7.187    0.0371
O  3 1666.15A   -6.720    0.1087
```

Databases in Cloudy

- Iso-electronic sequences (H and He like)
- H_2
- Stout (atoms & low ionization)
- Chianti (higher ionization)
- LAMDA (heavy-element molecules)
- Database print command
  - Reports all databases in use
  - The number of levels used
- Species "C+2" levels 40

Two level atom AGN3 Sec 3.5

- Excitation, deexcitation rates
- Transition probabilities
- Critical density
- Two limits
  - Low densities, every excitation leads to emission of a photon
  - high densities, levels are n LTE, photon emission proportional to $n_u A_{ul}$

$$4\pi j = n_u A_{ul} h\nu$$
$$[\mathrm{erg\ cm^{-3}\ s^{-1}}]$$

$$n_l q_{lu} n_e = n_u [A_{ul} + q_{ul} n_e]$$

$$\frac{n_u}{n_l} = \frac{q_{lu} n_e}{A_{ul} + q_{ul} n_e}$$

$$n_u + n_l = n$$

critical density

$$A_{ul} = q_{ul} n_{crit}$$

LDL

$$n_e \ll n_{crit}$$
$$4\pi j = n_e n_l q_{lu} h\nu$$

HDL

$$n_e \gg n_{crit}$$
$$4\pi j = n_e \frac{q_{lu}}{q_{ul}} A_{ul} h\nu$$

Table 3.15
Critical densities for collisional deexcitation

Ion	Level	n_e (cm^{-3})	Ion	Level	n_e (cm^{-3})
C II	$^2P^o_{3/2}$	5.0×10^1	O III	$^1D_2$	6.8×10^5
C III	$^3P^o_2$	5.1×10^5	O III	$^3P_2$	3.6×10^3
N II	$^1D_2$	6.6×10^4	O III	$^3P_1$	5.1×10^2
N II	$^3P_2$	3.1×10^2	Ne II	$^2P^o_{1/2}$	7.1×10^5
N II	$^3P_1$	8.0×10^1	Ne III	$^1D_2$	9.5×10^6
N III	$^2P^o_{3/2}$	1.5×10^3	Ne III	$^3P_0$	3.1×10^4
N IV	$^3P^o_2$	1.1×10^6	Ne III	$^3P_1$	2.1×10^5
O II	$^2D^o_{3/2}$	1.5×10^4	Ne V	$^1D_2$	1.3×10^7
O II	$^2D^o_{5/2}$	3.4×10^3	Ne V	$^3P_2$	3.5×10^4
S II	$^2D^o_{3/2}$	5.4×10^4	Ne V	$^3P_1$	6.2×10^3
S II	$^2D^o_{5/2}$	1.6×10^4			

NOTE: All values are calculated for $T = 10{,}000$ K.

Vary density over extreme range

- Plot emissivity vs density over wide range to see how emissivity changes
- Recombination line, [O III] forbidden lines
- varyn.in

Recombination lines

- $H^+ + e \rightarrow H^{0*} \rightarrow H^0$ + photons
- Critical densities of H I, He I, and He II optical lines are very high, n > 1e15 cm^{-3}, so they are usually in LDL
- Emissivity goes as n^2 for $n < 10^{20}$ cm^{-3}
- Case B predictions
- H I, He I, He II are the strongest in UV/ Opt/ IR
- Second row (C,N, O, Ne) & Fe in X-ray

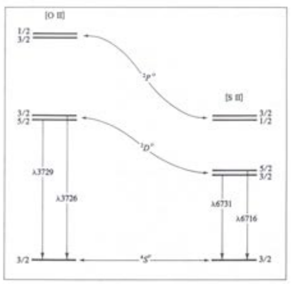
Forbidden lines

- [O III]
- $O^{++} + e \rightarrow O^{++*} + e \rightarrow O^{++} + e$ + photons
  - – $n_e\, n(O^{++})\, q_{ul}$
- Critical densities of many forbidden lines $n \sim 1e3 - 1e5\ cm^{-3}$, so they can be in LDL or HDL
- Emissivity goes as n^2 or n

Compute spectrum of clouds with two very different densities

- Hden = 4
- Hden = 14
  - – How will emission from these cloud compare?
  - – How can we "trick" the model into having roughly the same emission?

Density indicators



AGN3 Fig 5.7

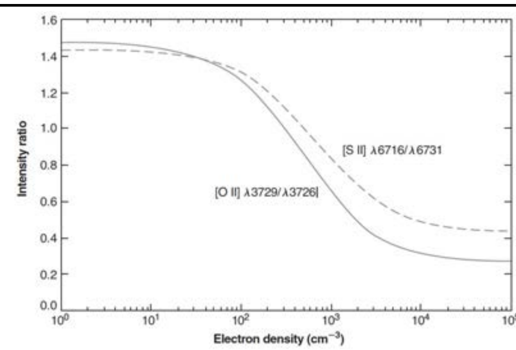
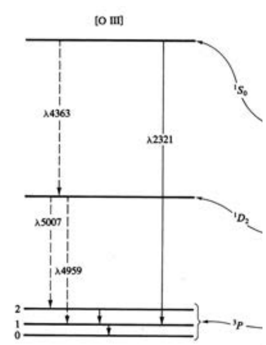


Figure 5.8
Calculated variation of [O II] (*solid line*) and [S II] (*dashed line*) intensity ratios as functions of n_e at T = 10,000 K. At other temperatures the plotted curves are very nearly correct if the horizontal scale is taken to be $n_e(10^4/T)^{1/2}$.

Temperature indicators



Temperature indicators

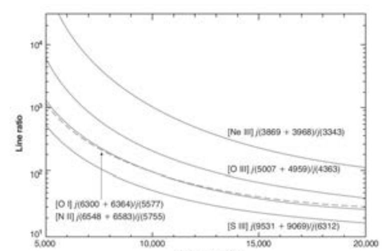


Figure 5.1
Four temperature sensitive forbidden line ratios are shown as a function of the electron temperature. The [O I] (solid line) and [N II] (dashed) ratios are nearly coincident, partially because of their similar excitation potentials. The ratios are shown in the low density limit (n_e = 1 cm^{-3}).

Radiative recombination edges

- Hrec3, hrec4.in in sims
- Hrec spreadsheet in sims
- Maybe do in x-rays instead? More common application

The ionization parameter

- U, the ratio of ionizing photon to hydrogen densities
- See Davidson & Netzer 1979

2.7 Photoionization of Heavy Elements

Finally, let us examine the ionization of the heavy elements, of which O, C, Ne, N, Si, and Fe, with abundances (by number) of order 10^{-3} to 10^{-4} that of H, are the most abundant. The ionization-equilibrium equation for any two successive stages of ionization i and $i+1$ of any element X may be written

$$n(X^{+i}) \int_{\nu_i}^{\infty} \frac{4\pi J_\nu}{h\nu} a_\nu(X^{+i}) d\nu = n(X^{+i}) \Gamma(X^{+i}) = n(X^{+i+1}) n_e \alpha_G(X^{+i}, T), \qquad (2.30)$$

where $n(X^{+i})$ and $n(X^{+i+1})$ are the number densities of the two successive stages of ionization; $a_\nu(X^{+i})$ is the photoionization cross section from the ground level of X^i

U and T(star) determine ionization

- No matter how intense the radiation field, how large the U, ions with ionization potentials higher than the highest energy in the SED cannot be produced