UNIVERSITY OF CALIFORNIA, SANTA BARBARA
Department of Physics

Physics 233 **Study Guide** **Winter 2014**

We have covered the following material: **Draine:** ch 1 - 10, 13 - 19, 21 - 24, 27, 29 - 32, 34 and **Osterbrock:** ch 1 - 5. I recommend you look over the section headers and figures and review all homework problems. I hope you take away from this class an understanding of the following concepts:

- Why diffuse plasmas are generally not in local thermodynamic equilibrium.
- What the spectrum of a diffuse plasma look like.
- What the principle cooling processes are in a diffuse gas. [Note, the answer depends on its temperature.]
- How the level populations determined in a collisionally excicted gas. [Know the law of mass action, the princple of detailed balance, and the definition of the critical density.
- How the level populations determined in a photoionized gas.
- The equations that describe photoionization equilibrium, the derivation of the Stromgren radius, the conditions required for Case B or Case A recombination, and the definition of the ionization parameter.
- How we calculate the equilibrium temperture of each of the following: HII regions, HI regions, molecular clouds, and dust grains.
- Know what determines the Energy levels in atoms, ions, and molecules, the rules for bound-bound transitions, and the processes describing bound-free and free-bound transitions.
- Be able to write down the Equation of radiative transfer and solve it for simple cases. Understand the difference between specific intensity, flux, and radiation pressure.
- Be familiar with the observed properties of interstellar dust and the inferred sizes and composition of the grains. Know how to apply corrections for reddening and extinction to observed spectra.
- Know what factors determine whether the interstellar medium in a galaxy can support multiple gas phases.
- Know how molecular hydrogen is formed and destroyed.
- Know why (and how) the CO molecular can be used to estimate the molecular gas mass in galaxies.

- Know when (and how) spectral lines from molecules can be used as a thermometer to estimate the gas temperature.

Physical Constants and Astronomical Data

New! Try my Physical Calculator. It is a JavaScript calculator with all of the constants below programmed into it.

Physical Constants

(converted to CGS units from the NIST Constant Index)

Name	Symbol	Number	Exp	CGS Units	Relative Error (ppm)
speed of light in a vacuum	c	2.99792458	10	$cm\ s^{-1}$	exact
Planck constant	h	6.6260755(40)	-27	erg s	0.60
	hbar	1.05457266(63)	-27	erg s	0.60
Gravitational constant	G	6.67259(85)	-8	$cm^3\ g^{-1}\ s^{-2}$	128
Electron charge	e	4.8032068(14)	-10	esu	0.30
Mass of electron	m_e	9.1093897(54)	-28	g	0.59
Mass of proton	m_p	1.6726231(10)	-24	g	0.59
Mass of neutron	m_n	1.6749286(10)	-24	g	0.59
Mass of hydrogen	m_H	1.6733	-24	g	--
Atomic mass unit	amu	1.6605402(10)	-24	g	0.59
Avagadro's number	N_A	6.0221367(36)	23		0.59
Boltzmann constant	k	1.380658(12)	-16	$erg\ k^{-1}$	8.5
Electron volt	eV	1.6021772(50)	-12	erg	~0.60
Radiation density constant	a	7.5646	-15	$erg\ cm^{-3}\ K^{-4}$	--
Stefan-Boltzmann constant	\sigma	5.67051(19)	-5	$erg\ cm^{-2}\ K^{-4}\ s^{-1}$	34
Fine structure constant	\alpha	7.29735308(33)	-3		0.045
Rydberg constant	R_{∞}	2.1798741(13)	-11	erg	0.60

Note: a "--" in the error column means that I have not found a good source for that constant, so the value quoted is just an approximation

---

Astronomical Units/Data

NAME	SYMBOL	NUMBER	EXP	CGS UNITS
Astronomical unit	AU	1.496	13	cm
Parsec	pc	3.086	18	cm
Light year	ly	9.463	17	cm
Solar mass	M_o	1.99	33	g
Solar radius	R_o	6.96	10	cm
Solar luminosity	L_o	3.9	33	erg s^{-1}
Solar Temperature	T_o	5.780	3	K

NAME	MASS (g)	RADIUS (cm)	PERIOD (yr)	SEMI-MAJOR (AU)	ECCENTRICITY
Mercury	3.303 26	2.439 8	2.4085 -1	3.87096 -1	0.205622
Venus	4.870 27	6.050 8	6.1521 -1	7.23342 -1	0.006783
Earth	5.976 27	6.378 8	1.00004 0	9.99987 -1	0.016684
Mars	6.418 26	3.397 8	1.88089 0	1.523705 0	0.093404
Jupiter	1.899 30	7.140 9	1.18622 1	5.204529 0	0.047826
Saturn	5.686 29	6.000 9	2.94577 1	9.575133 0	0.052754
Uranus	8.66 28	2.615 9	8.40139 1	1.930375 1	0.050363
Neptune	1.030 29	2.43 9	1.64793 2	3.020652 1	0.004014
Pluto	1. 25	1.2 8	2.47686 2	3.991136 1	0.256695

A Few Conversion Factors

CGS	-->	SI	Multiply by
centimeter (cm)		meter (m)	10^{-2}
gram (g)		kilogram (kg)	10^{-3}
erg		Joule (J)	10^{-7}
dyne (dyn)		newton (N)	10^{-5}

IONIZATION POTENTIALS[a]

Z	Element	Spectrum																		
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
1	H	13.598																				
2	He	24.587	54.416																			
3	Li	5.392	75.638	122.451																		
4	Be	9.322	18.211	153.893	217.713																	
5	B	8.298	25.154	37.930	259.368	340.217																
6	C	11.260	24.383	47.887	64.492	392.077	489.981															
7	N	14.534	29.601	47.448	77.472	97.888	552.057	667.029														
8	O	13.618	35.116	54.934	77.412	113.896	138.116	739.315	871.387													
9	F	17.422	34.970	62.707	87.138	114.240	157.161	185.182	953.886	1103.089												
10	Ne	21.564	40.962	63.45	97.11	126.21	157.93	207.27	239.09	1195.797	1362.164											
11	Na	5.139	47.286	71.64	98.91	138.39	172.15	208.47	264.18	299.87	1465.091	1648.659										
12	Mg	7.646	15.035	80.143	109.24	141.26	186.50	224.94	265.90	327.95	367.53	1761.802	1962.613									
13	Al	5.986	18.828	28.447	119.99	153.71	190.47	241.43	284.59	330.21	398.57	442.07	2085.983	2304.080								
14	Si	8.151	16.345	33.492	45.141	166.77	205.05	246.52	303.17	351.10	401.43	476.06	523.50	2437.676	2673.108							
15	P	10.486	19.725	30.18	51.37	65.023	230.43	263.22	309.41	371.73	424.50	479.57	560.41	611.85	2816.943	3069.762						
16	S	10.360	23.33	34.83	47.30	72.68	88.049	280.93	328.23	379.10	447.09	504.78	564.65	651.63	707.14	3223.836	3494.099					
17	Cl	12.967	23.81	39.61	53.46	67.8	98.03	114.193	348.28	400.05	455.62	529.26	591.97	656.69	749.74	809.39	3658.425	3946.193				
18	Ar	15.759	27.629	40.74	59.81	75.02	91.007	124.319	143.456	422.44	478.68	538.95	618.24	686.09	755.73	854.75	918	4120.778	4426.114			
19	K	4.341	31.625	45.72	60.91	82.66	100.0	117.56	154.86	175.814	503.44	564.13	629.09	714.02	787.13	861.77	968	1034	4610.955	4933.931		
20	Ca	6.113	11.871	50.908	67.10	84.41	108.78	127.7	147.24	188.54	211.270	591.25	656.39	726.03	816.61	895.12	974	1087	1157	5129.045	5469.738	
21	Sc	6.54	12.80	24.76	73.47	91.66	111.1	138.0	158.7	180.02	225.32	249.832	685.89	755.47	829.79	926.00						
22	Ti	6.82	13.58	27.491	43.266	99.22	119.36	140.8	168.5	193.2	215.91	265.23	291.497	787.33	861.33	940.36						
23	V	6.74	14.65	29.310	46.707	65.23	128.12	150.17	173.7	205.8	230.5	255.04	308.25	336.267	895.58	974.02						
24	Cr	6.766	16.50	30.96	49.1	69.3	90.56	161.1	184.7	209.3	244.4	270.8	298.0	355	384.30	1010.64						
25	Mn	7.435	15.640	33.667	51.2	72.4	95	119.27	196.46	221.8	248.3	286.0	314.4	343.6	404	435.3	1136.2					
26	Fe	7.870	16.18	30.651	54.8	75.0	99	125	151.06	235.04	262.1	290.4	330.8	361.0	392.2	457	489.5	1266.1				
27	Co	7.86	17.06	33.50	51.3	79.5	102	129	157	186.13	276	305	336	379	411	444	512	546.8	1403.0			
28	Ni	7.635	18.168	35.17	54.9	75.5	108	133	162	193	224.5	321.2	352	384	430	464	499	571	607.2	1547		
29	Cu	7.726	20.292	36.83	55.2	79.9	103	139	166	199	232	266	368.8	401	435	484	520	557	633	671	1698	
30	Zn	9.394	17.964	39.722	59.4	82.6	108	134	174	203	238	274	310.8	419.7	454	490	542	579	619	698	738	1856
31	Ga	5.999	20.51	30.71	64																	
32	Ge	7.899	15.934	34.22	45.71	93.5																
33	As	9.81	18.633	28.351	50.13	62.63	127.6															
34	Se	9.752	21.19	30.820	42.944	68.3	81.70	155.4														
35	Br	11.814	21.8	36	47.3	59.7	88.6	103.0	192.8													
36	Kr	13.999	24.359	36.95	52.5	64.7	78.5	111.0	126	230.39												
37	Rb	4.177	27.28	40	52.6	71.0	84.4	99.2	136	150	277.1											
38	Sr	5.695	11.030	43.6	57	71.6	90.8	106	122.3	162	177	324.1										
39	Y	6.38	12.24	20.52	61.8	77.0	93.0	116	129	146.52	191	206	374.0									
40	Zr	6.84	13.13	22.99	34.34	81.5																
41	Nb	6.88	14.32	25.04	38.3	50.55	102.6	125														
42	Mo	7.099	16.15	27.16	46.4	61.2	68	126.8	153													
43	Te	7.28	15.26	29.54																		
44	Ru	7.37	16.76	28.47																		
45	Rh	7.46	18.08	31.06																		
46	Pd	8.34	19.43	32.93																		
47	Ag	7.576	21.49	34.83																		

Planck Function: $B_\nu(T) = \frac{2h\nu^3}{c^2}\left[\frac{1}{e^{h\nu/k_2T}-1}\right]$

Wien's Law: $\lambda_{max} T = 0.29\ cm \cdot K$

Maxwell-Boltzmann Distribution:

$$f(v) = \frac{4}{\sqrt{\pi}}\left(\frac{m}{2k_2T}\right)^{3/2} v^2 e^{-mv^2/2k_2T}$$

$$f(E) = \frac{2N}{\sqrt{\pi}(k_2T)^{3/2}} E^{1/2} e^{-E/k_2T}\, dE$$

Saha Equation: $\frac{n_p n_e}{n_{1s}} = \left(\frac{2\pi m k_2 T}{h^2}\right)^{3/2} e^{-h\nu_0/k_2T}$

Boltzmann Equation: $\frac{N_j}{N_1} = \frac{g_j}{g_1} e^{-\Delta E/k_2T}$ where $g_J = 2J+1$

1.

$$\int e^{ax}dx = \frac{e^{ax}}{a}$$

2.

$$\int xe^{ax}dx = \frac{e^{ax}}{a}\left(x - \frac{1}{a}\right)$$

3.

$$\int x^2e^{ax}dx = \frac{e^{ax}}{a}\left(x^2 - \frac{2x}{a} + \frac{2}{a^2}\right)$$

4.

$$\begin{aligned}\int x^n e^{ax}dx &= \frac{x^n e^{ax}}{a} - \frac{n}{a}\int x^{n-1}e^{ax}dx \\ &= \frac{e^{ax}}{a}\left(x^n - \frac{nx^{n-1}}{a} + \frac{n(n-1)x^{n-2}}{a^2} - \cdots\frac{(-1)^n n!}{a^n}\right)\end{aligned}$$

5.

$$\int_0^\infty e^{-ax^2}dx = \frac{1}{2}\sqrt{\frac{\pi}{a}}$$

6.

$$\int_0^\infty e^{-ax^2}\cos bx\,dx = \frac{1}{2}\sqrt{\frac{\pi}{a}}e^{-b^2/4a}$$

7.

$$\int_{-b/2a}^\infty e^{-(ax^2+bx+c)}dx = \frac{1}{2}\sqrt{\frac{\pi}{a}}e^{(b^2-4ac)/4a}$$

8.

$$\int_{-\infty}^\infty e^{-(ax^2+bx+c)}dx = \sqrt{\frac{\pi}{a}}e^{(b^2-4ac)/4a}$$

9.

$$\int_0^\infty x^n e^{-ax}dx = \frac{\Gamma(n+1)}{a^{(n+1)}}$$

10.

$$\int_0^\infty x^m e^{-ax^2}dx = \frac{\Gamma[(m+1)/2]}{2a^{(m+1)/2}}$$

11.

$$\int_0^\infty e^{-(ax^2+b/x^2)}dx = \frac{1}{2}\sqrt{\frac{\pi}{a}}e^{-2\sqrt{ab}}$$

12.

$$\int_0^\infty \frac{x\,dx}{e^x-1} = \frac{1}{1^2}+\frac{1}{2^2}+\frac{1}{3^2}+\frac{1}{4^2}+\cdots = \frac{\pi^2}{6}$$