

## Wavelength Calibration Tables

The following tables give the wavelength, in vacuum microns, of the emission lines of Ar, Kr, and Xe, and the relative line strength. The data are from K. N. Rao *et al.* 1966, *Wavelength Standards in the Infrared* and M. Outred, *Tables of Atomic Spectral Lines for the 10000 Å to 40000 Å Region, Journal of Physical and Chemical Reference Data* (1978, Vol.7, No.1), Reprint #110. Library Catalog No. QC454 A809. Keep in mind that the Pen-Ray® lamps may produce relative intensities somewhat different than those listed. Furthermore, the thermal emission from the lamp envelope will probably dominate all but the very strongest lines longward of 3 μm, even though the quartz envelope should transmit to about 4.2 μm.

The HeNeAr calibration lamps in the 2.1-m and 4-m guiders produce primarily an Ar spectrum, with a few He and Ne lines thrown in. Identified spectra with all four gratings are kept in reference books in each of the telescope domes.

The table of OH lines (wavelength in vacuum microns) was generated from calculations of Coxon and Foster (for  $\lambda < 1.20 \mu\text{m}$ ) and from laboratory observations of Hubbard and Brault using the Solar FTS (for  $\lambda > 1.20 \mu\text{m}$ ). In the latter case, the hyperfine components were averaged, as their wavelength separation is less than the resolution limit of the CRSP. The second column gives the observed intensity in kR (Steed and Baker 1979, *Appl. Opt.*, **18**, 3386) of observed atmospheric lines. The third column, the laboratory intensities observed by Hubbard and Brault, may be less reliable, since they do not include the absorption by the atmosphere. The lines beyond 2.25 microns were not observed due to their faintness, although they are easily seen with CRSP; the wavelengths are calculated from the tables of Coxon and Foster.

Following the tables are sky spectra in the J, H, K, and L bands taken with grating 1, and in the J and K bands with grating 3, with prominent emission features identified. Short of 2.3 μm, these lines are predominantly OH airglow; longward of this wavelength, the emission features are telluric absorption lines seen in thermal emission. The O<sub>2</sub> 0-0 band at 1.27 μm is not explicitly identified, as it can decay over the course of a night. **NOTE:** Although the OH lines are well-identified individual lines, it is important to keep in mind that the thermal emission "lines" are in fact bands or groups of many sharp lines, and that their appearance will be a function of the resolution at which they are observed. The wavelengths identified were determined from a solar FTS spectrum convolved to the approximate spectral resolution of grating 1, and should be reliable for use with that grating. A number of features resolved with grating 1 are blended into a single feature with grating 3, with an intermediate effective wavelength. The resolutions of gratings 3 and 4 are sufficiently similar that sky features in grating 4 spectra may be identified with the grating 3 data. The OH lines in the I band are sufficiently weak as to be unreliable for wavelength calibration.

The OH and arc lists are also resident within IRAF in the /noao/lib/linelists/ directory for use with tasks such as 'identify'.

## REFERENCES

- Night Sky Lines --  
Steed and Baker 1979, *Appl. Opt.*, **18**, 3386.  
Coxon and Foster 1982, *Can. J. Phys.*, **60**, 41.  
Osterbrock and Martel 1992, *P.A.S.P.*, **104**, 76.  
Oliva and Origlia 1992, *Astron. Ap.*, **254**, 466.
- Spectral Calibration of Stars --  
Johnson and Mendez 1970, *Astron. J.*, **75**, 785.  
Strecker, Erickson, and Witteborn 1979, *Ap. J. Suppl.*, **41**, 501.  
Hall, Kleinmann, Scoville, and Ridgway 1981, *Ap. J.*, **248**, 898.  
Kleinmann and Hall 1986, *Ap. J. Suppl.*, **62**, 501.  
Livingston and Wallace 1991, *An Atlas of the Solar Spectrum in the Infrared from 1850 to 9000 cm<sup>-1</sup>*, NSO Technical Report #91-001, NOAO. (telluric absorption lines).

Emission Lines of Argon

The following table lists the vacuum wavelength of the infrared emission lines of argon, in microns, in the first column. In the second column are listed relative intensities; "B" indicates a line which is blended with its closest neighbor, and the tabulated intensity is that of the blend. (Ref. *Wavelength Standards in the Infrared*, K. N. Rao *et al.*, 1966, Outred, and KPNO linelists for  $\lambda < 1 \mu\text{m}$ ). He and Ne lines seen in HeNeAr lamp spectra are also listed.

0.91255	1200	1.21156	150	1.45997	11	2.03226	2
0.91512		1.21430	30	1.46005	B	2.05744	1
0.92270	700	1.21547	2	1.46384	30	2.05869	[He]
0.92941		1.23468	30	1.46543	30	2.06219	50
0.93568	100	1.23597	10	1.46974	4	2.06528	2
0.94618		1.24062	100	1.47432	5	2.07393	2
0.96604	1000	1.24427	300	1.47898	B	2.07402	B
0.97872	300	1.24595	100	1.50506	100	2.08167	2
1.00548	1	1.24911	200	1.51768	25	2.09918	30
1.01662		1.25577	2	1.53061	40	2.10416	1
1.03356		1.25985	[Ne]	1.53335	9	2.13387	1
1.04729	500	1.26251	2	1.53530	7	2.11303	B
1.04809	12	1.27057	100	1.53573	3	2.15401	8
1.05092	B	1.27369	30	1.54068	6	2.17141	[Ne]
1.06765	200	1.27497	12	1.54510	2	2.20456	1
1.06847	10	1.28062	200	1.55597	2	2.20832	8
1.07039		1.29367	40	1.57392	2	2.21187	1
1.07621		1.29602	500	1.58211	18	2.22602	
1.08333	[He]	1.30118	200	1.59040	10	2.25366	[Ne]
1.08839	5	1.30320	2	1.59939	25	2.31395	20
1.09537		1.32176	200	1.61271	1	2.33794	[Ne]
1.10819	10	1.32317	200	1.61844	4	2.38515	1
1.11095	3	1.32345	200	1.62685		2.39731	20
1.11461	[Ne]	1.32763	500	1.64411	13	2.42563	[Ne]
1.11806	[Ne]	1.33059	4	1.65244	30	2.43717	[Ne]
1.13968	8	1.33168	800	1.65538	8	2.44545	[Ne]
1.14450	12	1.33338	6	1.67446	9	2.47832	[Ne]
1.14707	6	1.33708	1000	1.69452	500	2.51321	25
1.14912	120	1.34102	100	1.70071	[He]	2.54916	3
1.15835	1	1.35031	30	1.74497	11	2.55122	8
1.16173	[Ne]	1.35079	1000	1.74067	2	2.56680	10
1.16719	200	1.35479	8	1.74500	B	2.86202	200
1.16908	1	1.35773	12	1.78289	5	2.86979	50
1.17227	10	1.36030	40	1.79196	40	2.87829	500
1.17364	9	1.36264	400	1.84232	2	2.88431	100
1.17700	[Ne]	1.36823	200	1.84328	10	2.91348	50
1.17927	[Ne]	1.37223	1000	1.84334	B	2.92807	20
1.18877	4	1.38295	B	1.84345	B	2.97968	250
1.18999	1	1.38321	9	1.98229	5	3.09962	10
1.19882	[Ne]	1.39113	8	1.99086		3.13330	100
1.19466	12	1.39144	50	1.99505		3.30788	15
1.19471	B	1.39966	1	1.99712	4	3.31484	15
1.20299	2	1.40975	150	2.00311	2	3.32934	10
1.20696	[Ne]	1.42577	B	2.00744	1	3.64920	10

Emission Lines of Krypton

The following table lists the vacuum wavelength of the infrared emission lines of krypton, in microns, in the first column. In the second column are listed the relative intensities. (Ref. *Wavelength Standards in the Infrared*, K. N. Rao *et al.*, 1966). The data from Outred short of 1.08  $\mu\text{m}$  do not yield good solutions to lamp spectra taken with CRSP, and they are thus not included in this table.

1.08779	80	1.52137	140	2.01517	5	3.99775	30
1.11902	100	1.52438	1700	2.02153	140	4.03171	130
1.12608	200	1.53307	130	2.02978	14	4.06965	20
1.12622	150	1.53392	1500	2.04295	300		
1.14606	500	1.53762	700	2.04526	140		
1.17956	150	1.54782	200	2.05494	75		
1.18226	1500	1.56397	40	2.08114	14		
1.20004	600	1.56853	180	2.09301	95		
1.20805	160	1.58244	120	2.09821	18		
1.21211	140	1.58951	100	2.10271	15		
1.21268	40	1.63196	50	2.11713	600		
1.22079	800	1.64703	70	2.12026	10		
1.27859	150	1.65775	70	2.12909	5		
1.28019	120	1.67311	200	2.13618	5		
1.28654	100	1.67897	2000	2.14442	56		
1.28824	750	1.68581	1000	2.14967	13B		
1.29888	25	1.68951	2400	2.19085	1800		
1.30259	30	1.69014	1600	2.22460	11		
1.31810	1100	1.69404	1800	2.24918	120		
1.32443	110	1.70746	40	2.25189	7		
1.33415	120	1.71034	600	2.25516	13		
1.36261	1000	1.72354	30	2.29106	9		
1.36379	2400	1.73724	700	2.33467	180		
1.36621	800	1.74092	120	2.35088	70		
1.37148	200	1.76216	150	2.42672	120		
1.37426	600	1.78476	650	2.42988	180		
1.38366	150	1.80071	700	2.47416	19		
1.38866	500	1.81043	80	2.47752	90		
1.39276	700	1.81723	2600	2.52407	600		
1.39427	200	1.81900	90	2.67684	50		
1.39778	150	1.84234	20	2.69076	40		
1.40495	550	1.85860	150	2.86182	180		
1.41081	140	1.87015	300	2.86633	1000		
1.41601	50	1.87901	170	2.87774	150		
1.43445	30	1.87929	50	2.88302	140		
1.43513	800	1.88028	200	2.92274	40		
1.44062	180	1.90554	9	2.92445	300		
1.44307	2000	1.91963	13	3.06718	300		
1.44730	140	1.92329	30	3.09875	300		
1.47385	1600	1.95966	17	3.92945	50		
1.47667	550	1.97181	6	3.95680	40		
1.47695	450	1.97630	5B	3.95992	500		
1.49660	400	1.99212	17	3.96004	500		
1.50094	120	2.00177	36	3.99657	60		

Emission Lines of Xenon

The following table lists the vacuum wavelength of the infrared emission lines of xenon, in microns, in the first column. In the second column are listed the relative intensities. (Ref. *Wavelength Standards in the Infrared*, K. N. Rao *et al.*, 1966).

1.05308	120	2.51663	70
1.07097	50	2.60276	20
1.08413	1000	2.62761	3500
1.08983	120	2.65182	4500
1.10883	300	2.83891	300
1.11302	40	2.85901	1000
1.11442	20	2.93923	300
1.16173	50	2.94562	80
1.17455	300	2.96575	20
1.17968	150	2.98216	10
1.18605	160	3.02613	1000
1.19564	40	3.04839	2000
1.20881	60	3.05126	20
1.22386	200	3.08025	800
1.22611	20	3.10776	9900
1.25937	150	3.12843	10
1.26268	2500	3.13446	90
1.35478	120	3.16167	800
1.36608	3000	3.23109	10
1.41462	2000	3.27479	2000
1.42448	600	3.32747	10
1.43688	200	3.36757	7000
1.46648	50	3.40238	150
1.47368	5000	3.40842	80
1.51039	20	3.43446	1000
1.54226	2000	3.47537	150
1.55614	50	3.50800	5000
1.59839	150	3.62192	90
1.60442	50	3.62418	30
1.60577	500	3.65185	500
1.65590	30	3.67984	800
1.67326	2000	3.68586	80
1.73305	1500	3.86969	10
1.87932	500	3.87377	30
2.01926	80	3.87486	20
2.02678	2000	3.88788	70
2.13789	20	3.89504	300
2.14759	300	3.89597	150
2.24128	60	3.89731	120
2.26244	10	3.94839	70
2.31996	1500	3.95299	50
2.32860	50	3.99657	200
2.44504	100		
2.47091	60		
2.48314	5500		
2.51528	200		

OH Lines (Vacuum Microns: Osterbrock & Martel; Hubbard & Brault; Coxon & Foster)

			2nd column: Observed Intensity in kR (Steed & Baker)			3rd column: Lab Intensity in Arbitrary Units (Hubbard & Brault)					
0.93787			1.29212	0.17	0.42	1.55098	0.25	1.96	1.79348	0.05	0.80
0.94424			1.29431	0.09	0.22	1.55179	0.20	0.59	1.79940	1.42	1.80
0.94796			1.29857	0.15	0.29	1.55404	0.55	3.35	1.80679	0.18	0.84
0.95221			1.30216	0.32	0.77	1.55462	-----	1.73	1.81185	0.50	1.63
0.97940	0.04		1.30528	0.21	0.49	1.55702	0.15	1.00	1.82110	-----	0.67
0.98750	0.09		1.30852	0.39	1.11	1.55977	0.70	2.43	1.82542	0.05	1.18
0.99175	0.10		1.31278	0.18	1.07	1.56313	-----	1.12	1.95181	0.15	0.38
0.99648	0.10		1.31567	0.19	1.11	1.56316	0.35	2.56	1.95611	0.12	0.64
1.00163	0.15		1.32110	0.10	0.47	1.56550	1.05	2.30	1.95932	0.05	0.32
1.00854	0.07		1.32366	0.27	0.88	1.56570	-----	1.81	1.96425	0.30	0.47
1.01270	0.10		1.33019	0.01	0.32	1.57025	0.28	1.12	1.96990	0.15	0.22
1.01747	0.16		1.33247	0.04	0.55	1.57603	0.10	0.53	1.97029	0.35	0.62
1.02896	0.28		1.34208	0.06	0.31	1.57821	0.15	0.82	1.97362	0.05	0.34
1.03759	0.22		1.39859	0.05	0.25	1.58303	-----	0.75	1.97515	0.20	0.46
1.04214	0.30		1.40222	0.15	0.58	1.58332	2.30	4.89	1.97718	0.52	0.54
1.04720	0.20		1.40446	-----	0.55	1.58481	0.90	2.08	1.98397	0.22	0.28
1.05278	0.10		1.40588	-----	0.43	1.58693	0.25	0.87	2.00082	1.05	1.15
1.07139	0.10		1.40698	-----	0.32	1.58973	0.10	0.33	2.00332	0.35	0.54
1.07319	0.20		1.40867	0.10	1.35	1.59159	-----	0.31	2.01933	0.15	0.38
1.07541	0.25		1.41027	0.05	0.58	1.59726	0.50	1.55	2.02759	1.00	0.92
1.08324	0.40		1.41070	0.05	0.77	1.60308	1.53	3.67	2.03395	0.55	0.58
1.08989	0.10		1.41340	0.18	2.01	1.60798	0.65	2.31	2.04127	1.28	1.25
1.09266	0.24		1.41629	0.22	0.22	1.61286	1.71	4.74	2.04993	0.27	1.23
1.09515	0.10		1.41861	0.20	1.96	1.61947	0.63	2.16	2.05636	1.05	1.21
1.09755	0.35		1.41929	-----	0.45	1.62354	1.27	4.11	2.06729	0.03	0.52
1.10095	0.10		1.42272	-----	0.93	1.63172	0.28	1.64	2.07290	0.77	0.94
1.10300	0.28		1.42929	0.07	0.32	1.63418	0.12	0.60	2.08603	0.20	0.37
1.10726	0.05		1.43420	-----	0.67	1.63513	0.65	2.83	2.09096	0.33	0.61
1.10902	0.15		1.43444	0.30	3.42	1.63604	0.10	0.38	2.10680	0.22	0.14
1.11562	0.05		1.43567	-----	1.78	1.63885	0.25	1.06	2.10966	-----	0.07
1.13130	0.12		1.43744	-----	0.69	1.64147	0.20	0.62	2.11057	-----	0.34
1.13314	0.15		1.44691	-----	1.35	1.64421	-----	1.43	2.11159	0.24	0.21
1.13544	0.10		1.45190	0.60	3.26	1.64476	0.70	0.98	2.11561	0.12	0.13
1.14379	0.40		1.45640	0.35	1.97	1.64764	-----	1.58	2.11766	0.38	0.28
1.15389	0.32		1.46048	0.35	4.07	1.64790	0.50	1.55	2.12325	0.15	0.15
1.15654	0.02		1.46651	0.14	1.85	1.65023	0.75	1.35	2.12497	0.41	0.24
1.15919	0.35		1.46984	0.35	3.43	1.65539	0.30	0.65	2.12791	0.05	0.11
1.16281	0.12		1.47022	-----	0.52	1.65863	-----	0.49	2.13180	-----	0.17
1.16508	0.30		1.47133	-----	0.33	1.66110	0.10	0.75	2.13260	0.16	0.11
1.16965	0.08		1.47400	0.10	1.18	1.66892	-----	0.44	2.15050	-----	0.07
1.17163	0.20		1.47556	0.05	0.74	1.66921	2.30	2.88	2.15073	1.20	0.51
1.17882	0.08		1.47724	0.15	1.30	1.67088	0.83	1.22	2.15121	-----	0.05
1.20003	0.12		1.47837	0.15	2.18	1.67325	0.30	0.53	2.15376	0.30	0.24
1.20072	0.20		1.47998	0.30	2.26	1.67636	0.15	0.21	2.15807	0.15	0.10
1.20244	0.18		1.48057	0.26	1.25	1.68405	0.30	0.90	2.17111	0.25	0.17
1.20311	0.24		1.48330	0.62	3.10	1.69037	1.45	2.15	2.18022	0.70	0.36
1.20559	0.07	0.09	1.48644	0.20	3.30	1.69551	0.52	1.35	2.18735	0.35	0.23
1.21226	0.54	0.34	1.48862	-----	0.73	1.70088	1.80	2.80	2.19556	0.90	0.39
1.21359	0.20	0.16	1.48877	0.78	2.98	1.70783	0.70	1.35	2.20524	0.30	0.18
1.21550	0.05	0.07	1.49091	0.10	1.18	1.71236	1.20	2.51	2.21255	0.80	0.24
1.21964	0.11	0.13	1.49319	0.26	1.45	1.72104	0.36	1.00	2.22479	0.28	0.11
1.22293	0.40	0.30	1.50067	-----	0.34	1.72486	0.70	1.77	2.23127	0.50	0.23
1.22578	0.18	0.21	1.50261	-----	0.51	1.72829	0.18	0.41	2.24603	0.10	0.11
1.22870	0.46	0.41	1.50528	-----	0.99	1.73309	0.32	0.69	2.25180	0.25	0.17
1.23259	0.17	0.38	1.50555	1.95	6.45	1.73511	0.20	0.62	2.26906		
1.23516	0.30	0.41	1.50640	-----	0.33	1.73597	0.20	0.39	2.27420	0.15	0.13
1.24009	0.11	0.20	1.50689	0.66	2.67	1.73838	0.40	1.01	2.29393		
1.24230	0.19	0.37	1.50882	0.23	1.08	1.73867	0.40	0.93	2.29856		
1.24827	0.04	0.13	1.51137	0.10	0.39	1.74270	0.30	0.94	2.32101		
1.25024	0.09	0.25	1.51870	0.38	1.98	1.74499	0.72	0.83	2.32494		
1.25891	0.05	0.15	1.52410	1.41	4.65	1.75013	0.27	0.34			
1.27528	0.15	0.30	1.52878	0.58	2.93	1.75060	0.08	0.41			
1.27644	0.21	0.34	1.53324	1.15	5.91	1.75294	0.08	0.51			
1.27825	0.24	0.47	1.53953	0.40	2.73	1.76532	2.00	1.82			
1.28070	0.23	0.39	1.54321	1.08	5.03	1.76718	0.70	0.79			
1.28346	0.08	0.20	1.54621	0.10	0.44	1.76984	0.18	0.35			
1.29057	0.57	0.94	1.54744	-----	0.31	1.78114	0.08	0.55			
			1.55008	0.20	0.97	1.78803	1.20	1.34			