6k. Radiometry

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6k-1. Blackbody Radiation. These tables contain various radiation functions derived from the Planck function

$$W(\lambda, T) = \frac{c_1}{\lambda^5(e^{c_2/\lambda T} - 1)}$$

where $W(\lambda,T)$ is defined as the power radiated per unit wavelength interval at wavelength λ by unit area of a blackbody at temperature T K. c_2 was taken to be 1.438 cm K. The constant c_1 does not enter into the functions here tabulated.

The maximum value of $W(\lambda,T)$ is given by

$$W_{max}(T) = 1.290 \times 10^{-15}T^5 \qquad \text{W/(cm}^2 \cdot \mu\text{m)}$$

while the Stefan-Boltzmann function is given by

$$\int_0^\infty W\, d\lambda = 5.679 \times 10^{-12}T^4 \qquad \text{W/cm}^2$$

6k-2. Optical Pyrometry (Narrow-band Radiation). When an optical pyrometer which has been calibrated to read the true temperature of a blackbody source is sighted on a nonblack source, it reads values of "brightness temperature" $T_{br}(\lambda,T)$ lower than the true temperature T K. Brightness temperature is related to true temperature through the following formula, which is derived from Planck's formula:

$$\ln \epsilon(\lambda, T) = \frac{c_2}{\lambda}\left(\frac{1}{T} - \frac{1}{T_{br}}\right)$$

where c_2 = 1.4350 cm · K (international temperature scale of 1948)

$\epsilon(\lambda,T)$ = emittance of the source at wavelength λ and temperature T

Commercial radiation pyrometers, although broad-band, do not utilize the complete spectrum of radiant energy. Hence there is no simple formula for precise calculation of the effect on temperature readings of varying emittance of the source. Table 6k-10 was calculated using the relation

$$T(\text{K}) = \frac{T_{apparent}(\text{K})}{\epsilon_t^{\frac{1}{4}}}$$

where ϵ_t is the total emittance. It may be used to estimate approximate corrections in radiation pyrometry.

TABLE 6k-1. BLACKBODY RADIATION FUNCTIONS*

λT, cm·deg	$\frac{W(\lambda, T)}{W_{max}(T)}$	$\frac{\int_0^\lambda W\,d\lambda}{\int_0^\infty W\,d\lambda}$	λT, cm·deg	$\frac{W(\lambda, T)}{W_{max}(T)}$	$\frac{\int_0^\lambda W\,d\lambda}{\int_0^\infty W\,d\lambda}$
0.050	2.999×10^{-7}	1.316×10^{-9}	0.155	3.032×10^{-1}	1.610×10^{-2}
0.051	4.775×10^{-7}	2.184×10^{-9}	0.160	3.457×10^{-1}	1.979×10^{-2}
0.052	7.452×10^{-7}	3.552×10^{-9}	0.165	3.892×10^{-1}	2.396×10^{-2}
0.053	1.142×10^{-6}	5.665×10^{-9}	0.170	4.332×10^{-1}	2.862×10^{-2}
0.054	1.718×10^{-6}	8.871×10^{-9}	0.175	4.772×10^{-1}	3.379×10^{-2}
0.055	2.545×10^{-6}	1.366×10^{-8}	0.180	5.208×10^{-1}	3.946×10^{-2}
0.056	3.709×10^{-6}	2.068×10^{-8}	0.185	5.636×10^{-1}	4.561×10^{-2}
0.057	5.326×10^{-6}	3.084×10^{-8}	0.190	6.053×10^{-1}	5.225×10^{-2}
0.058	7.544×10^{-6}	4.532×10^{-8}	0.195	6.455×10^{-1}	5.935×10^{-2}
0.059	1.054×10^{-5}	6.568×10^{-8}	0.200	6.840×10^{-1}	6.690×10^{-2}
0.060	1.455×10^{-5}	9.395×10^{-8}	0.22	8.169×10^{-1}	1.011×10^{-1}
0.061	1.985×10^{-5}	1.327×10^{-7}	0.24	9.126×10^{-1}	1.405×10^{-1}
0.062	2.676×10^{-5}	1.853×10^{-7}	0.26	9.712×10^{-1}	1.834×10^{-1}
0.063	3.570×10^{-5}	2.558×10^{-7}	0.28	9.972×10^{-1}	2.282×10^{-1}
0.064	4.713×10^{-5}	3.493×10^{-7}	0.30	9.971×10^{-1}	2.736×10^{-1}
0.065	6.613×10^{-5}	4.721×10^{-7}	0.32	9.771×10^{-1}	3.185×10^{-1}
0.066	7.984×10^{-5}	6.319×10^{-7}	0.34	9.432×10^{-1}	3.621×10^{-1}
0.067	1.025×10^{-4}	8.380×10^{-7}	0.36	8.999×10^{-1}	4.040×10^{-1}
0.068	1.305×10^{-4}	1.101×10^{-6}	0.38	8.512×10^{-1}	4.438×10^{-1}
0.069	1.649×10^{-4}	1.435×10^{-6}	0.40	7.997×10^{-1}	4.813×10^{-1}
0.070	2.066×10^{-4}	1.856×10^{-6}	0.42	7.475×10^{-1}	5.164×10^{-1}
0.071	2.571×10^{-4}	2.380×10^{-6}	0.44	6.961×10^{-1}	5.492×10^{-1}
0.072	3.176×10^{-4}	3.030×10^{-6}	0.46	6.464×10^{-1}	5.796×10^{-1}
0.073	3.897×10^{-4}	3.831×10^{-6}	0.48	5.990×10^{-1}	6.079×10^{-1}
0.074	4.751×10^{-4}	4.810×10^{-6}	0.50	5.543×10^{-1}	6.341×10^{-1}
0.075	5.757×10^{-4}	5.999×10^{-6}	0.52	5.125×10^{-1}	6.583×10^{-1}
0.076	6.934×10^{-4}	7.436×10^{-6}	0.54	4.735×10^{-1}	6.807×10^{-1}
0.077	8.304×10^{-4}	9.162×10^{-6}	0.56	4.375×10^{-1}	7.013×10^{-1}
0.078	9.891×10^{-4}	1.122×10^{-5}	0.58	4.042×10^{-1}	7.204×10^{-1}
0.079	1.172×10^{-3}	1.367×10^{-5}	0.60	3.735×10^{-1}	7.381×10^{-1}
0.080	1.382×10^{-3}	1.657×10^{-5}	0.62	3.453×10^{-1}	7.544×10^{-1}
0.081	1.621×10^{-3}	1.997×10^{-5}	0.64	3.193×10^{-1}	7.694×10^{-1}
0.082	1.893×10^{-3}	2.395×10^{-5}	0.66	2.956×10^{-1}	7.834×10^{-1}
0.083	2.201×10^{-3}	2.859×10^{-5}	0.68	2.737×10^{-1}	7.963×10^{-1}
0.084	2.548×10^{-3}	3.398×10^{-5}	0.70	2.537×10^{-1}	8.083×10^{-1}
0.085	2.938×10^{-3}	4.020×10^{-5}	0.72	2.354×10^{-1}	8.194×10^{-1}
0.086	3.373×10^{-3}	4.735×10^{-5}	0.74	2.185×10^{-1}	8.297×10^{-1}
0.087	3.859×10^{-3}	5.555×10^{-5}	0.76	2.030×10^{-1}	8.392×10^{-1}
0.088	4.397×10^{-3}	6.491×10^{-5}	0.78	1.888×10^{-1}	8.481×10^{-1}
0.089	4.993×10^{-3}	7.556×10^{-5}	0.80	1.758×10^{-1}	8.564×10^{-1}
0.090	5.651×10^{-3}	8.763×10^{-5}	0.82	1.638×10^{-1}	8.641×10^{-1}
0.091	6.373×10^{-3}	1.013×10^{-4}	0.84	1.528×10^{-1}	8.713×10^{-1}
0.092	7.165×10^{-3}	1.166×10^{-4}	0.86	1.426×10^{-1}	8.780×10^{-1}
0.093	8.030×10^{-3}	1.339×10^{-4}	0.88	1.332×10^{-1}	8.843×10^{-1}
0.094	8.973×10^{-3}	1.532×10^{-4}	0.90	1.246×10^{-1}	8.901×10^{-1}
0.095	9.998×10^{-3}	1.747×10^{-4}	0.92	1.166×10^{-1}	8.956×10^{-1}
0.096	1.111×10^{-2}	1.986×10^{-4}	0.94	1.093×10^{-1}	9.007×10^{-1}
0.097	1.231×10^{-2}	2.252×10^{-4}	0.96	1.024×10^{-1}	9.055×10^{-1}
0.098	1.360×10^{-2}	2.546×10^{-4}	0.98	9.613×10^{-2}	9.100×10^{-1}
0.099	1.500×10^{-2}	2.870×10^{-4}	1.0	9.029×10^{-2}	9.143×10^{-1}
0.100	1.649×10^{-2}	3.228×10^{-4}	1.1	6.679×10^{-2}	9.319×10^{-1}
0.105	2.563×10^{-2}	5.591×10^{-4}	1.2	5.035×10^{-2}	9.451×10^{-1}
0.110	3.785×10^{-2}	9.162×10^{-4}	1.3	3.862×10^{-2}	9.551×10^{-1}
0.115	5.350×10^{-2}	1.431×10^{-3}	1.4	3.007×10^{-2}	9.629×10^{-1}
0.120	7.281×10^{-2}	2.145×10^{-3}	1.5	2.375×19^{-2}	9.690×10^{-1}
0.125	9.588×10^{-2}	3.099×10^{-3}	1.6	1.899×10^{-2}	9.738×10^{-1}
0.130	1.227×10^{-1}	4.336×10^{-3}	1.7	1.536×10^{-2}	9.777×10^{-1}
0.135	1.530×10^{-1}	5.897×10^{-3}	1.8	1.255×10^{-2}	9.808×10^{-1}
0.140	1.866×10^{-1}	7.822×10^{-3}	1.9	1.035×10^{-2}	9.834×10^{-1}
0.145	2.232×10^{-1}	1.015×10^{-2}	2.0	8.612×10^{-3}	9.856×10^{-1}
0.150	2.622×10^{-1}	1.290×10^{-2}			

* Table by Reynolds et al., ref. 4.

TABLE 6k-2. TOTAL BLACKBODY RADIATION*

T, K	$\int_0^\infty W\,d\lambda$, W/cm²	$W_{max}(T)$, W/(cm²·μm)
1	5.679 × 10⁻¹²	1.290 × 10⁻¹⁵
5	3.549 × 10⁻⁹	4.030 × 10⁻¹²
10	5.679 × 10⁻⁸	1.290 × 10⁻¹⁰
15	2.875 × 10⁻⁷	9.794 × 10⁻¹⁰
20	9.086 × 10⁻⁷	4.127 × 10⁻⁹
30	4.600 × 10⁻⁶	3.134 × 10⁻⁸
40	1.454 × 10⁻⁵	1.321 × 10⁻⁷
50	3.549 × 10⁻⁵	4.030 × 10⁻⁷
60	7.360 × 10⁻⁵	1.003 × 10⁻⁶
70	1.364 × 10⁻⁴	2.168 × 10⁻⁶
80	2.326 × 10⁻⁴	4.226 × 10⁻⁶
90	3.726 × 10⁻⁴	7.616 × 10⁻⁶
100	5.679 × 10⁻⁴	1.290 × 10⁻⁵
110	8.315 × 10⁻⁴	2.077 × 10⁻⁵
120	1.178 × 10⁻³	3.209 × 10⁻⁵
130	1.622 × 10⁻³	4.789 × 10⁻⁵
140	2.181 × 10⁻³	6.936 × 10⁻⁵
150	2.875 × 10⁻³	9.794 × 10⁻⁵
160	3.722 × 10⁻³	1.352 × 10⁻⁴
170	4.743 × 10⁻³	1.831 × 10⁻⁴
180	5.961 × 10⁻³	2.437 × 10⁻⁴
190	7.401 × 10⁻³	3.194 × 10⁻⁴
200	9.086 × 10⁻³	4.127 × 10⁻⁴
210	1.105 × 10⁻²	5.267 × 10⁻⁴
220	1.331 × 10⁻²	6.647 × 10⁻⁴
230	1.590 × 10⁻²	8.301 × 10⁻⁴
240	1.885 × 10⁻²	1.027 × 10⁻³
250	2.218 × 10⁻²	1.260 × 10⁻³
260	2.595 × 10⁻²	1.532 × 10⁻³
270	3.018 × 10⁻²	1.851 × 10⁻³
280	3.491 × 10⁻²	2.220 × 10⁻³
290	4.017 × 10⁻²	2.645 × 10⁻³
300	4.600 × 10⁻²	3.134 × 10⁻³
310	5.245 × 10⁻²	3.692 × 10⁻³
320	5.955 × 10⁻²	4.328 × 10⁻³
330	6.735 × 10⁻²	5.047 × 10⁻³
340	7.589 × 10⁻²	5.860 × 10⁻³
350	8.522 × 10⁻²	6.774 × 10⁻³
360	9.538 × 10⁻²	7.799 × 10⁻³
370	1.065 × 10⁻¹	8.944 × 10⁻³
380	1.184 × 10⁻¹	1.022 × 10⁻²
390	1.314 × 10⁻¹	1.164 × 10⁻²
400	1.454 × 10⁻¹	1.321 × 10⁻²
410	1.605 × 10⁻¹	1.494 × 10⁻²
420	1.768 × 10⁻¹	1.686 × 10⁻²
430	1.942 × 10⁻¹	1.896 × 10⁻²
440	2.128 × 10⁻¹	2.127 × 10⁻²
450	2.328 × 10⁻¹	2.380 × 10⁻²
460	2.542 × 10⁻¹	2.656 × 10⁻²
470	2.771 × 10⁻¹	2.958 × 10⁻²
480	3.015 × 10⁻¹	3.286 × 10⁻²
490	3.274 × 10⁻¹	3.643 × 10⁻²
500	3.549 × 10⁻¹	4.030 × 10⁻²
520	4.152 × 10⁻¹	4.904 × 10⁻²
540	4.829 × 10⁻¹	5.922 × 10⁻²
560	5.585 × 10⁻¹	7.103 × 10⁻²
580	6.426 × 10⁻¹	8.465 × 10⁻²
600	7.360 × 10⁻¹	1.003 × 10⁻¹
620	8.392 × 10⁻¹	1.182 × 10⁻¹
640	9.527 × 10⁻¹	1.385 × 10⁻¹
660	1.087	1.615 × 10⁻¹
680	1.215	1.875 × 10⁻¹
700	1.364	2.168 × 10⁻¹
720	1.527	2.496 × 10⁻¹
740	1.703	2.862 × 10⁻¹
760	1.895	3.270 × 10⁻¹
780	2.102	3.724 × 10⁻¹
800	2.326	4.226 × 10⁻¹
820	2.567	4.782 × 10⁻¹
840	2.827	5.394 × 10⁻¹
860	3.106	0.667 × 10⁻¹
880	3.406	6.806 × 10⁻¹
900	3.726	7.616 × 10⁻¹
920	4.069	8.500 × 10⁻¹
940	4.434	9.465 × 10⁻¹
960	4.824	1.052
980	5.239	1.166
1000	5.679	1.290
1020	6.147	1.424
1040	6.644	1.569

T, K	$\int_0^\infty W\,d\lambda$, W/cm²	$W_{max}(T)$, W/(cm²·μm)
1060	7.170	1.726
1080	7.726	1.895
1100	8.315	2.077
1120	8.937	2.273
1140	9.591	2.483
1160	10.29	2.709
1180	11.01	2.951
1200	11.78	3.209
1220	12.58	3.486
1240	13.43	3.781
1260	14.32	4.096
1280	15.25	4.431
1300	16.22	4.789
1320	17.25	5.169
1340	18.32	5.572
1360	19.43	6.001
1380	20.59	6.455
1400	21.81	6.936
1420	23.09	7.446
1440	24.42	7.986
1460	25.80	8.556
1480	27.24	9.158
1500	28.75	9.794
1520	30.31	10.46
1540	31.94	11.17
1560	33.63	11.92
1580	35.39	12.70
1600	37.22	13.52
1620	39.12	14.39
1640	41.08	15.30
1660	43.12	16.26
1680	45.24	17.26
1700	47.43	18.31
1720	49.71	19.42
1740	52.06	20.57
1760	54.50	21.78
1780	57.01	23.05
1800	59.61	24.37
1820	62.31	25.75
1840	65.09	27.20
1860	67.97	28.71
1880	70.94	30.29
1900	74.01	31.94
1920	77.18	33.65
1940	80.44	35.44
1960	83.81	37.31
1980	87.29	39.25
2000	90.86	41.27
2100	110.5	52.67
2200	133.1	66.47
2300	159.0	83.01
2400	188.5	102.7
2500	221.8	126.0
2600	259.5	153.2
2700	301.8	185.1
2800	349.1	222.0
2900	401.7	264.5
3000	460.0	313.4
3100	524.5	369.2
3200	595.5	432.8
3300	673.5	504.7
3400	758.9	586.0
3500	852.2	677.4
3600	953.8	779.9
3700	1065	894.4
3800	1184	1022
3900	1314	1164
4000	1454	1321
4500	2328	2380
5000	3549	4030
5500	5197	6491
6000	7360	10030
6500	10140	14960
7000	13640	21680
7500	17970	30610
8000	23260	42260
8500	29640	57230
9000	37260	76160
9500	46260	99800
10000	56790	12900

* Table by Reynolds et al., ref. 4.

TABLE 6k-3. TOTAL EMITTANCE

Material	Temperature, K	Type*	Total† emittance	References‡
Aluminum:				
Polished	370–630	*h*	0.04–0.06	1
Heavily oxidized	360–800	*h*	0.2–0.33	1
Electrolytically oxid., 4–10 μm thick	310	*h*	0.72–0.83	2
Aluminum oxide	80–500	*n*	0.76–	1
	1200–1750		0.45–0.41	
Aluminum oxide layer:				
0.25 μm thick	311	*n*	0.06	4
0.50 μm thick	311	*n*	0.11	
1.0 μm thick	311	*n*	0.30	
2.0 μm thick	311	*n*	0.65	
3.0 μm thick	311	*n*	0.70	
4.0 μm thick	311	*n*	0.70	
7.0 μm thick	311	*n*	0.75	
Antimony:				
Polished	300–350	*n*	0.28–0.31	3
Beryllium	1100–1300–1480	*n*	0.41–0.57–0.87	1
Bismuth	350		0.34	3, 2
Brass:				
Highly polished	500–610	*h*	0.02	2
Polished	373	*n*	0.06	1
Oxidized	450–590	*n*	0.56–0.64	1
Bronze, 4–7 aluminum:				
Polished	450–1270	*n*	0.03–0.06	1
Oxidized	450–1270	*n*	0.08–0.16	1
Cadmium	80–300	*h*	0.03	1
Carbon:				
Rough	1200–2000	*n*	0.84–0.81	1
Polished	1200–2000	*n*	0.82–0.79	1
Ceria (cerium dioxide):				
Powder coating	670–1070–1350–2250	*n*	0.53–0.30–0.90–0.93	1
Heat treated	1300–1700–1900	*h*	0.65–0.40–0.50	1
Chromium	370–600–750–1220	*n*	0.06–0.10–0.42	1
	80	*h*	0.07	1
Cobalt	350–600–1030	*n*	0.20–0.28–0.74	1
Copper:				
Polished	80–800	*h*	0.02–0.03	1
Polished pure	300–700–970–1410	*h*	0.04–0.07–0.19–0.15	2
Oxidized	300–600–800–1100	*h*	0.38–0.47–0.59–0.87	1
Polished	80–380–1160	*n*	0.02–0.01–0.02	1
Oxidized	80–540–700–1078	*n*	0.66–0.78–0.90–0.93	1
Gold:				
Polished	80–1100	*h*	0.01–0.07	1
Graphite:				
ATJ	700–1400–2700	*n*	0.81–0.74–0.90	1
Pyrolytic, basal plane	1600–1800–2700	*n*	0.67–0.49–0.35	1
Pyrolytic, *c* plane	1570–1900–1900–2500	*n*	1.0–1.0–0.82	1
Pyrolytic film on ATJ	2000–2600	*h*	0.65–0.73	1
Iron and steel:				
Armco and pure, polished	160–1100	*h*	0.05–0.25	1
	600–1100	*n*	0.2–0.56	
Cast, polished	300–915–1355	*h*	0.21–0.21–0.28	1
Cast, oxidized	360–800–1350	*h*	0.62–0.73–0.73	2
Wrought, smooth	300–1800	*h*	0.27	2
Smooth sheet, rolled	800–1350	*h*	0.48–0.60	2
Electrolytic, oxidized	310–700	*h*	0.78–	2
	1025–1800		0.89–0.94	

TABLE 6k-3. TOTAL EMITTANCE (*Continued*)

Material	Temperature, K	Type*	Total† emittance	References‡
Stainless steel 310	800–1400	*h*	0.25	1
Stainless steel 310 (grid blasted, oxidized)	400–1050	*h*	0.74–0.84	1
Stainless steel 347 (stably (oxidized)	600–1400	*h*	0.86–0.91	1
Stainless steel 303 (stably oxidized)	600–1400	*h*	0.75–0.87	1
Stainless steel 18-8, polished	350–650	*n*	0.15–0.20	1
oxidized	350–650		0.84	
Stainless steel, AISI 316, polished	80–900 1100–1300–1420	*n*	0.19–0.35–0.62–0.32	1
Iron oxide, Fe_2O_3	310–1350	*h*	0.82–0.89	
Lead:				
Polished	310–530	*h*	0.04–0.08	3
Gray, oxidized	270–470	*h*	0.28	2
Oxidized at 473 K	473	*h*	0.63	4
Magnesium, polished	410–490	*h*	0.12	1
Manganin, bright, rolled	391	*n*	0.048	4
Mercury, pure, clean	273–373		0.09–0.12	2
Molybdenum:				
Vapor blasted	400–1800	*h*	0.07–0.21	1
Oxidized	600–810	*h*	0.81	1
Polished	1600–2300–2900	*n*	0.13–0.28–0.28	1
Oxidized	600–800	*n*	0.83	1
Nickel:				
Polished	80–1100	*h*	0.02–0.17	1
Polished	80–550–1450	*n*	0.07–0.04–0.19	1
Oxidized	420–700–980	*n*	0.07–0.39–0.47	1
Nickel-chromium Alloys:				
Inconel X, stably oxidized	580–1370	*h*	0.89–0.93	1
Inconel X, polished	80–800–1200	*h*	0.06–0.12–0.23	1
René 41, oxidized	550–1350	*n*	0.78–0.87	1
Inconel-NBSA-418 coating	750–1250	*n*	0.68–0.64	1
Nichrome 80-20, oxidized	480–900–1200	*h*	0.62–0.67–0.78	1
Nickel-copper Alloys:				
K Monel 5700	80–900–1300	*n*	0.14–0.20–0.30	1
Monel 400	300	*h*	0.12	1
Nickel-molybdenum alloys:				
Haynes Alloy C, oxidized	580–1370	*h*	0.90–0.96	1
Inor-8, polished	340–1240	*n*	0.15–0.25	1
Niobium-tungsten alloys:				
90-10, polished	1970–2580	*h*	0.27	1
85-15, polished	1970–2580	*h*	0.26	1
Palladium	400–1520	*n*	0.02–0.17	1
Platinum, cold rolled	420–1500 690–1700	*n* *h*	0.02–0.16 0.09–0.17	1
Rhodium:				
As received	490–1520	*n*	0.02–0.09	1
Polished	420–1080–1250	*n*	0.012–0.068–0.034	2
Plated on stainless steel	80	*h*	0.075	1
Silver:				
Polished	650–1100	*h*	0.03–0.04	1
Thermally etched	460–1100	*h*	0.04–0.08	1
Tantalum:				
Polished, gas adsorbed	480–1480	*h*	0.1–0.25	1
Polished	1600–2920	*h*	0.17–0.30	1

TABLE 6k-3. TOTAL EMITTANCE (*Continued*)

Material	Temperature, K	Type*	Total† emittance	References‡
Tantalum carbide, polished	1600–3000	*n*	0.2–0.33	1
Tantalum nitride, polished	800–1500	*n*	0.74–0.80–0.60	1
Tellurium	295	*n*	0.22	4
Tin, polished	310–360	*h*	0.05	2
Titanium:				
Polished	900	*h*	0.24	1
Electropolished	250–370	*h*	0.1–0.13	1
Titanium:				
Oxidized	640–950–1100	*h*	0.54–0.60	1
Oxidized, 306 hr at 813 K	360–700	*n*	0.35–0.48	1
Oxidized, 306 hr at 580 K	360–700	*n*	0.11–0.20	1
Titanium-aluminum alloy:				
A-110-AT, polished	80–600–1100	*n*	0.12–0.20–0.52	1
Titanium-manganese Alloys:				
C-110M, AMS 4908,				
polished	300–900	*n*	0.05–0.17	1
oxidized	300–900	*n*	0.50–0.61	1
RS-120, oxidized	600–1100	*h*	0.67–0.72	1
Tungsten:				
Polished	400–2000–3400	*h*	0.04–0.24–0.34	1
Polished	1400–3000	*n*	0.15–0.32	1
Filament	300–2300	*n*	0.032–0.28	4
Uranium	1200	*h*	0.35	1
Zinc:				
Pure, polished	300–530	*n*	0.02–0.06	2
Oxidized	300–470–800	*n*	0.28–0.14–0.11	2
Zirconium, as received	1150–1250–1450–1860	*n*	0.33–0.39–0.26–0.32	1
Water	273–373	*n*	0.92–0.96	4
Ice:				
Smooth, H_2O	273	*n*	0.96	4
Rough crystals	273	*n*	0.985	4
Glass	293	*n*	0.94	4
Lacquer:				
White	373	*n*	0.925	4
Black matte	373	*n*	0.97	4
Oil paints, all colors	273–373	*n*	0.92–0.96	4
Enamel	295	*n*	0.90–0.95	4
Candle soot	273–373	*n*	0.952	4
Plaster	273–373	*n*	0.91	4
Paper	373	*n*	0.92	4
Rubber, hard, glossy plate	297	*n*	0.945	4
Quartz (fused)	295	*n*	0.932	4

* *n* = normal (emittance), *h* = hemispherical (emittance).

† The emittances correspond to the given temperatures. Linear interpolation between points fairly accurate.

‡ References are on p. 6-204 following Table 6k-5.

TABLE 6k-4. LOW-TEMPERATURE TOTAL HEMISPHERICAL EMITTANCES*

Material	80 K	150 K	300 K
Gold, polished	0.018	0.020	0.023
Platinum black on gold†	0.95	1.00	1.0
Parson's optical black, heavy coat	0.68	0.88	1.0
3M velvet, 9564 black, heavy coat	0.80	0.80	1.0
Gold black on gold, heavy coat	0.75	0.90	0.95
Fuller black 3811	0.60	0.70	0.82
Midland sicon black 7 × 942	0.70	0.70	0.70
Anodized aluminum, 28 μm thick	0.60	0.82	0.86

* Taken from graphs in ref. 7.

† Special preparation, see ref. 7.

TABLE 6k-5. NORMAL SPECTRAL EMITTANCE OF METALS AND ALLOYS AT $\lambda = 0.665\ \mu m$

Material	Temperature, K	Normal spectral emittance*	Ref.
Cobalt	1180–1530	0.39–0.37	1
Copper:			
Polished	1080	0.15	2
Oxidized	1080	0.15	2
As received	1080	0.25	2
Germanium	1000–2000	0.50–0.53†	1
Gold	1220–1330	0.50–0.53‡	1
Graphite:			
GBE	1080–1905	0.80–0.71	2
GBH	1080–1905	0.86–0.77	2
7087	1080–1800	0.89–0.79	2
Iron, Armco, 2 μm rough	1130–1430	0.38–0.35	1
Molybdenum	1000–1800–2900	0.4–0.32–0.31†	1
Nickel:			
Polished	1080–1500	0.36–0.32	1
Oxidized	1100–1500	0.86–0.82	1
Osmium	1200–1800–2500	0.55–0.38–0.39	1
Palladium	1100–1550	0.40–0.33	1
Platinum:			
Polished	1100–1900	0.28–0.29†	1
Cold rolled	1100–1500	0.32–0.42†	1
Pyroceram 9608	1135–1465	0.48	5
Rhenium	1800–3000	0.41†	1
Rhodium	1120–1820	0.24–0.17	1
Silicon	1000–1700	0.64–0.46†	1
Tantalum:			
Polished	2300–3300	0.36†	1
Aged	1100–1600–2800	0.49–0.44–0.41†	1
Thorium, heat treated	1300–1650	0.38	1
Titanium, polished	1250–1650	0.48–0.47†	1
Zirconium	1000–2000	0.43–0.41†	1
Zirconium oxide	1155–1800	0.4–0.55	5
Stainless steels:			
321, bright	1080–1465	0.38–0.30	2
321, dull oxidized	1080–1465	0.67–0.52	2
AM 350, bright	1080–1465	0.38–0.33	2
AM 350, oxidized	1135–1465	0.75–0.58	2
PH 15-7 Mo, 5–40 μm rough	1080–1465	0.40–0.36	2
Cobalt alloy N-155:			
Polished	1080–1465	0.36–0.28	2
Oxidized	1080–1465	0.72–0.70	2
Inconel X:			
Polished	1080–1465	0.44–0.39	2
Oxidized	1080–1465	0.89–0.66	2
Bronze:			
4–7 Al	1080–1245	0.65	2
6–8 Al	1080–1245	0.72–0.70	2

* The emittances correspond to the given temperatures. Linear interpolation between points is fairly accurate.
† At $\lambda = 0.65\ \mu m$.
‡ At $\lambda = 0.64\ \mu m$.

References for Tables 6k-3 to 6k-5

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6k-3. Emittance of Solids

ϵ_n = total normal emittance (emission of radiant energy of all wavelengths normal to the specified surface divided by the corresponding emission from a blackbody)

ϵ_h = total hemispherical emittance (emittance for radiation into hemisphere above emitting surface)

For metals: $\frac{\epsilon_h}{\epsilon_n} = (1.05\text{–}1.33)$ (most metals ~ 1.2)

For nonmetals: $\frac{\epsilon_h}{\epsilon_n} = (0.95\text{–}1.05)$ (most nonmetals ~ 0.98)

These relations are strictly valid only for specularly reflecting surfaces.

Emittances depend on such factors as surface roughness, work hardening, impurity content, and surface contamination. Tabulated values, while critically selected, can therefore only serve as a guide.

ϵ_λ = spectral emittance (emission of radiant energy within a small wavelength increment at wavelength λ, divided by the corresponding emission from a blackbody). The quantity depends on the angle of emission. For pyrometric temperature determination, the normal spectral emittance at about 0.665 μm is of importance.

r_λ = spectral reflectance (fraction of incident unpolarized radiation of wavelength λ reflected into the hemisphere above the reflecting surface). The quantity depends on the angle of incidence.

In consequence of Kirchhoff's law and the Helmholtz reciprocity relations:

$$\epsilon_\lambda = 1 - r_\lambda$$

if the angles of emission and incidence are the same. The relation is valid for specular and diffuse reflection and may be used to determine emittances from reflectance measurements. A corresponding relation does not in general exist for total emittances and reflectances. Off-normal emitted radiation is in general partially polarized.

TABLE 6k-6. SPECTRAL EMITTANCE OF OXIDES FOR $\lambda = 0.65\ \mu m$*

Material	Range of observed values	Probable value for the oxide formed on smooth metal
Aluminum oxide	0.22–0.40	0.30
Beryllium oxide	0.07–0.37	0.35
Cerium oxide	0.58–0.80	
Chromium oxide	0.60–0.80	0.70
Cobalt oxide	....	0.75
Columbium oxide	0.55–0.71	0.70
Copper oxide	0.60–0.80	0.70
Iron oxide	0.63–0.98	0.70
Magnesium oxide	0.10–0.43	0.20
Nickel oxide	0.85–0.96	0.90
Thorium oxide	0.20–0.57	0.50
Tin oxide	0.32–0.60	
Titanium oxide	....	0.50
Uranium oxide	....	0.30
Vanadium oxide	....	0.70
Yttrium oxide	....	0.60
Zirconium oxide	0.18–0.43	0.40
Alumel (oxidized)	....	0.87
Cast iron (oxidized)	....	0.70
Chromel P (90 Ni, 10 Cr) (oxidized)	....	0.87
80 Ni, 20 Cr (oxidized)	....	0.90
60 Ni, 24 Fe, 16 Cr (oxidized)	....	0.83
55 Fe, 37.5 Cr, 7.5 Al (oxidized)	....	0.78
70 Fe, 23 Cr, 5 Al, 2 Co (oxidized)	....	0.75
Constantan (55 Cu, 45 Ni) (oxidized)	....	0.84
Carbon steel (oxidized)	....	0.80
Stainless steel (18-8) (oxidized)	....	0.85
Porcelain	0.25–0.50	

The emittance of oxides and oxidized metals depends to a large extent upon the roughness of the surface. In general, higher values of emissivity are obtained on the rougher surfaces.

* American Institute of Physics, "Temperature, Its Measurement and Control in Science and Industry," p. 1313, Reinhold Publishing Corporation, New York, 1941.

TABLE 6k-7. SPECTRAL EMITTANCE OF OXIDES FOR λ = 0.665 μm*

Material	Temperature, °C	Emittance	Year
Aluminum oxide, 99.5%	1000–1600	0.175	1952
Beryllium oxide, white (hot pressed)	927–1063	0.21	1948
Magnesium oxide	1000–1470	0.18	1957
Nickel oxide, NiO	816–1204	0.87–0.82	1957
Silicon dioxide	1000–1600	0.18	1952
Tantalum oxide	816–1204	0.78	1957
Thorium oxide	1268–1800	0.40	1952

The emittance of white oxides depends strongly on purity. Only low values are shown.
* See ref. 13, p. 6-205.

TABLE 6k-8. THERMAL-CONTROL MATERIALS*

Material	α_s/ϵ	Absorptance† α_s at 70°F	Emittance ϵ at 70°F
Paints:			
White silicate on Al	0.15	0.13	0.85
White epoxy	0.25	0.22	0.89
Al-silicone	0.92	0.22	0.24
Al-acrylic	0.85	0.41	0.48
Black acrylic	1.06	0.93	0.88
Black silicone	1.15	0.89	0.77
Optical solar reflector (second surface mirror, Ag)	0.0625	0.05	0.80
Stainless steel, sandblasted (AI SI 410)	0.88	0.75	0.85
6061 Al, rolled, chemically cleaned	2.7	0.16	0.06
Al foil, annealed	2.4	0.12	0.04
Al, sandblasted	2.0	0.42	0.21
Al, Reynolds wrap foil:			
Dull side	5.0	0.2	0.04
Shiny side	6.3	0.18	0.03
Inconel quilted	3.2	0.38	0.12
Inconel, X-foil	6.6	0.66	0.10
Hanovia gold on René 41	6.0	0.53	0.09
Gold, high purity on Al	9.0	0.27	0.03

* Space Materials Handbook, *Air Force Rept.* AFML-TR 60-40, suppl. 2, 1966. See reference for additional materials, details on composition, and stability.
† α_s = absorptance for solar radiation.

TABLE 6k-9. RELATION BETWEEN BRIGHTNESS TEMPERATURE AND TRUE TEMPERATURE FOR VARIOUS VALUES OF SPECTRAL EMISSIVITY AT $\lambda = 0.65$ μm*

Brightness temp., °C....	800	1000	1200	1400	1600	1800	2000
Emissivity ϵ (0.65 μm)	True temp., °C						
0.05	982	1265	1567	1846	2236	2609	3011
0.10	934	1194	1467	1752	2054	2370	2704
0.15	909	1156	1413	1681	1958	2248	2549
0.20	891	1130	1377	1632	1895	2168	2451
0.30	867	1095	1329	1567	1813	2064	2320
0.40	850	1071	1296	1525	1757	1995	2236
0.50	837	1053	1272	1493	1717	1944	2174
0.60	827	1039	1252	1467	1685	1905	2125
0.70	819	1027	1236	1447	1659	1872	2087
0.80	812	1017	1222	1429	1636	1844	2054
0.90	805	1008	1210	1413	1617	1821	2025

* American Institute of Physics, "Temperature, Its Measurement and Control in Science and Industry," Reinhold Publishing Corporation, New York, 1941.

TABLE 6k-10. RELATION BETWEEN APPARENT AND TRUE TEMPERATURE FOR VARIOUS VALUES OF THE TOTAL EMISSIVITY*

Apparent temp., °C	100	200	400	600	800	1000	1200	1400	1600	1800
Total emissivity ϵ_t	True temp., °C									
0.05	422	686	1137	1567	1993	2317	2841	3264	3687	4110
0.10	316	536	913	1275	1632	1989	2345	2701	3057	3413
0.15	264	460	799	1126	1449	1771	2093	2415	2736	3058
0.20	231	410	725	1029	1330	1629	1929	2228	2527	2827
0.30	189	347	630	904	1175	1446	1717	1987	2258	2528
0.40	164	307	568	823	1075	1327	1579	1830	2082	2333
0.50	146	278	523	763	1002	1240	1478	1716	1954	2192
0.60	132	255	489	718	945	1173	1400	1628	1855	2082
0.70	121	238	461	680	900	1119	1337	1556	1775	1993
0.80	113	223	437	649	861	1073	1284	1496	1707	1919
0.90	106	211	417	623	828	1034	1239	1445	1650	1855

* American Institute of Physics, "Temperature, Its Measurement and Control in Science and Industry," Reinhold Publishing Corporation, New York, 1941.

TABLE 6k-11. EFFICIENCIES OF ILLUMINANTS*

Lamp	Rating, or specification	Eff.	Ab. eff.
Acetylene	1.0 liters/hr	0.67	0.0010
Arc, electric:			
Carbon, enclosed d-c	6.6 amp opal globe and reflector	5.9	0.0087
Carbon, open d-c	9.6 amp clear globe	11.8	0.0173
High intensity	150 amp bare arc	18.5	0.0272
Magnetite d-c	6.6 amp	21.6	0.0318
Gas burner, open flame	Bray high pressure	0.22	0.00032
Gas mantle, incandescent:			
High pressure	0.578 lumen/(Btu. hr)	2.0	0.0030
Low pressure	0.350 lumen/(Btu. hr)	1.2	0.0018
Incandescent electric carbon filament:			
First commercial	....	1.6	0.0023
Squirted cellulose	....	3.3	0.0048
Metalized	....	4.0	0.0059
Tungsten filaments:			
Vacuum	25 watt 120 volt (1,000 hr life)	10.6	0.0156
Gas-filled	40 watt 120 volt (1,000 hr life)	11.6	0.0171
Gas-filled	60 watt 120 volt (1,000 hr life)	13.9	0.0204
Gas-filled	100 watt 120 volt (750 hr life)	16.3	0.0239
Gas-filled	1,000 watt 120 volt (1,000 hr life)	21.6	0.0318
Gas-filled	5,000 watt 120 volt (75 hr life)	32.8	0.0482
Fluorescent lamps:			
General line	20 watt standard warm white (T12)	50.0	0.0735
General line	40 watt standard warm white (T12)	64.0	0.0940
General line	90 watt standard warm white (T17)	58.0	0.0850
Slimline	96T8 (120 ma) standard warm white	76.0	0.1115
Slimline	96T12 (425 ma) standard warm white	69.0	0.1015
General line	40 W daylight (T12)	54.0	0.0795
General line	40 W green (T12)	84.0	0.1235
General line	40 W blue (T12)	33.0	0.0485
General line	40 W red (T12)	3.6	0.0053
Mercury lamps	400 W (E1)	50.0	0.0735
	1,000 W (A6)	65.0	0.0955
Sodium	10,000 lumen	55.0	0.0808

The rating listed is the commercial rating of the lamp. The absolute efficiency is the equivalent power in light flux (0.556 μm) per watt input. Efficiency is given in lumens per watt input.

* "Handbook of Chemistry and Physics," 49th ed., p. E-196, Chemical Rubber Publishing Company, 1968–1969. Compiled by J. M. Smith and C. E. Weitz.

TABLE 6k-12. APPROXIMATE BRIGHTNESS OF VARIOUS LIGHT SOURCES*

Source		Lamberts†
Natural sources:		
Clear sky	Average brightness	2.5
Sun (as observed from earth's surface)	At meridian	519,000
Sun (as observed from earth's surface)	Near horizon	1,885
Moon (as observed from earth's surface)	Bright spot	0.8
Combustion sources:		
Candle flame (sperm)	Bright spot	3.1
Kerosene flame (flat wick)	Bright spot	3.8
Illuminating-gas flame	Fishtail burner	1.3
Welsbach mantle	Bright spot	20.0
Acetylene flame	Mees burner	34.0
Incandescent electric lamps:		
Carbon filament		165
Metalized carbon filament (Gem)		300
Tungsten filament	Vacuum lamp, 10 lumens per watt	650
Tungsten filament	Gas-filled lamp, 20 lumens per watt	3,800
Tungsten filament	750-watt projector lamp, 26 lumens per watt	7,500
Fluorescent lamps:		
20 watt T12 standard warm white		1.67
40 watt T12 standard warm white		2.10
96T12 standard warm white		2.052
Electric-arc lamps:		
Plain carbon arc	Positive crater 7 mm non-rotating	55,000
High-intensity carbon arc	Positive crater 8 mm non-rotating	125,000
High-intensity carbon arc	Positive crater 13.6 mm non-rotating	220,000
High-intensity carbon arc	Positive crater	314,000
Mercury lamps:		
Low-pressure mercury arc	50-in. a-c rectified tube	6.6
400 W (H1)		440
1,000 W (A6)	Water-cooled	94,000
Sodium lamps	10,000 lumens	18

* "Handbook of Chemistry and Physics," 49th ed., pp. E-196, 197, Chemical Rubber Publishing Company, 1968–1969. Compiled by J. M. Smith and C. E. Weitz.

† To convert lamberts to foot-lamberts multiply by 929. To convert lamberts to candelas/cm² divide by π.

TABLE 6k-13. PROPERTIES OF TUNGSTEN*

Temp., K	Normal brightness new candela/cm²	Spectral emissivity		Color emissivity	Total emissivity	Brightness temp. 0.65 μm	Color temp.
		0.65 μm	0.467 μm				
300	....	0.472	0.505	.....	0.032		
400	....	.....	.....	.....	0.042		
500	....	.....	.....	.....	0.053		
600	....	.....	.....	.....	0.064		
700	....	.....	.....	.....	0.076		
800	....	.....	.....	.....	0.088		
900	....	.....	.....	.....	0.101		
1000	0.0001	0.458	0.486	0.395	0.114	966	1007
1100	0.001	0.456	0.484	0.392	0.128	1059	1108
1200	0.006	0.454	0.482	0.390	0.143	1151	1210
1300	0.029	0.452	0.480	0.387	0.158	1242	1312
1400	0.11	0.450	0.478	0.385	0.175	1332	1414
1500	0.33	0.448	0.476	0.382	0.192	1422	1516
1600	0.92	0.446	0.475	0.380	0.207	1511	1619
1700	2.3	0.444	0.473	0.377	0.222	1599	1722
1800	5.1	0.442	0.472	0.374	0.236	1687	1825
1900	10.4	0.440	0.470	0.371	0.249	1774	1928
2000	20.0	0.438	0.469	0.368	0.260	1861	2032
2100	36	0.436	0.467	0.365	0.270	1946	2136
2200	61	0.434	0.466	0.362	0.279	2031	2241
2300	101	0.432	0.464	0.359	0.288	2115	2345
2400	157	0.430	0.463	0.356	0.296	2198	2451
2500	240	0.428	0.462	0.353	0.303	2280	2556
2600	350	0.426	0.460	0.349	0.311	2362	2662
2700	500	0.424	0.459	0.346	0.318	2443	2769
2800	690	0.422	0.458	0.343	0.323	2523	2876
2900	950	0.420	0.456	0.340	0.329	2602	2984
3000	1260	0.418	0.455	0.336	0.334	2681	3092
3100	1650	0.416	0.454	0.333	0.337	2759	3200
3200	2100	0.414	0.452	0.330	0.341	2837	3310
3300	2700	0.412	0.451	0.326	0.344	2913	3420
3400	3400	0.410	0.450	0.323	0.348	2989	3530
3500	4200	0.408	0.449	0.320	0.351	3063	3642
3600	5200	0.406	0.447	0.317	0.354	3137	3754

* "Handbook of Chemistry and Physics," 49th ed., p. E-228, Chemical Rubber Publishing Company, 1968-1969. Roeser and Wensel, National Bureau of Standards.

TABLE 6k-14. THE EMITTANCE OF WELL-DEFINED TUNGSTEN RIBBON AS A FUNCTION OF WAVELENGTH AT TEMPERATURES BETWEEN 1600 AND 2800 K*

Wavelength, μm	Emissivity						
	1600 K	1800 K	2000 K	2200 K	2400 K	2600 K	2800 K
0.25	0.447	0.442	0.437	0.430	0.424	0.416	0.410
0.30	0.482	0.478	0.474	0.470	0.465	0.461	0.456
0.35	0.479	0.476	0.473	0.470	0.467	0.464	0.461
0.40	0.481	0.477	0.475	0.471	0.468	0.464	0.461
0.50	0.469	0.465	0.462	0.458	0.455	0.451	0.448
0.60	0.455	0.451	0.448	0.444	0.441	0.438	0.434
0.70	0.444	0.440	0.436	0.432	0.428	0.423	0.419
0.80	0.431	0.426	0.420	0.414	0.409	0.404	0.400
0.90	0.413	0.407	0.401	0.396	0.390	0.386	0.383
1.0	0.390	0.386	0.382	0.376	0.373	0.371	0.368
1.1	0.367	0.364	0.361	0.358	0.355	0.353	0.352
1.2	0.344	0.343	0.342	0.341	0.340	0.339	0.338
1.3	0.322	0.322	0.323	0.323	0.324	0.324	0.325
1.4	0.300	0.302	0.306	0.308	0.310	0.311	0.313
1.5	0.281	0.284	0.288	0.292	0.296	0.299	0.302
1.6	0.264	0.268	0.273	0.278	0.283	0.288	0.292
1.8	0.234	0.241	0.247	0.255	0.262	0.268	0.275
2.0	0.210	0.219	0.227	0.235	0.243	0.251	0.259
2.2	0.190	0.201	0.210	0.218	0.228	0.236	0.245
2.4	0.176	0.187	0.196	0.206	0.215	0.224	0.233
2.6	0.164	0.175	0.185	0.194	0.205	0.214	0.224

* J. C. De Vos, *Physica* **20**, 690 (1954).

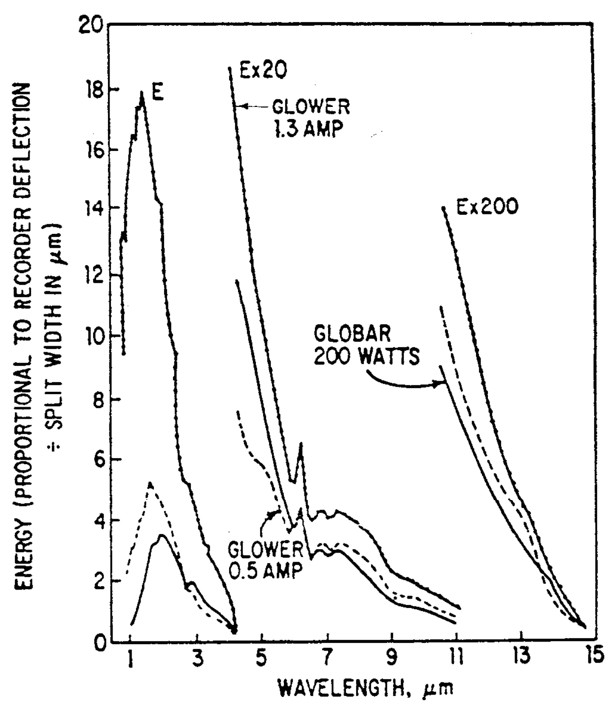

FIG. 6k-1. Characteristics of globar and glower sources.

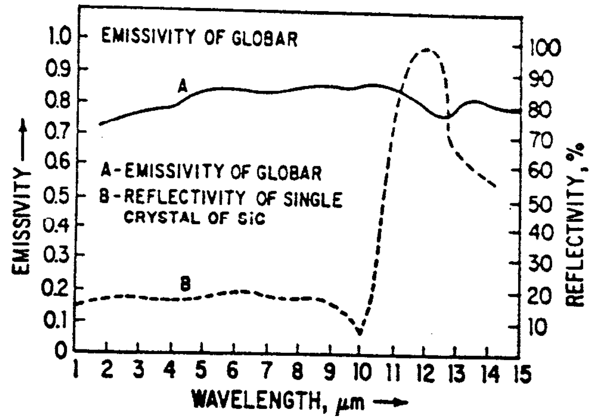

FIG. 6k-2. Emissivity of globar.

6k-4. Stellar Radiation. Brightness of stars as seen by any photoreceiver may be expressed as a stellar magnitude, related to the effective irradiance I in watts/cm² received from the star:

$$\text{Stellar magnitude } m = -2.5 \log_{10} \frac{I}{I_0}$$

The effective irradiance I from the star as seen by a photoreceiver is

$$I = \int_0^\infty J(\lambda)\sigma(\lambda)\, d\lambda$$

where $J\lambda$ = spectral distribution of radiation received from the star, in watts/cm² per wavelength increment $d\lambda$. $J(\lambda)$ for stars approximates blackbody distribution for the assumed surface temperatures.

$\sigma(\lambda)$ = photoreceiver's spectral-response function normalized at the response peak.

For visual magnitude

$$I_0 = \tfrac{1}{685} \times 10^{-(24.18/2.5)} = 3.1 \times 10^{-13}\ \mathrm{W/cm^2}$$

(Cf. definition of lumen, page 6-5; definition of stellar magnitude, "Smithsonian Tables," 8th ed., Table 798.)

Star brightness as seen by photoreceivers other than the eye is also expressed as a stellar magnitude (e.g., bolometric magnitude, photographic magnitude). The magnitude scales are generally adjusted by setting I_0 so that a class A0 star (surface temperature 11,000 K) appears of the same magnitude to each photoreceiver. For stars at other temperatures the effective-irradiance integral can be evaluated to obtain an index, which when added to visual magnitude gives the star's magnitude as seen by other receivers. Early stellar photometry used the non-color-sensitized (blue-sensitive) photographic plate; the difference between photographic and visual magnitude was called color index. Difference between bolometric and visual magnitude was called heat index. Indices for the principal spectral classes of stars and for several photoreceivers are given in Table 6k-15.

TABLE 6k-15. COLOR INDICES OF VARIOUS STELLAR SPECTRAL CLASSES

Spectral class	Approx eff. surface temp., K	Index			
		Photographic, visual	Bolometric, visual	S4 photosurface, visual	PbS, visual
B0	20,000	−0.30	−1.4	−0.15	+0.2
A0	11,000	0	0	0	0
F0	7,500	+0.33	+0.6	+0.30	−0.4
gG0	5,000	+0.70	+0.4	+0.7	−1.0
gK0	4,200	+1.12	+0.1	+1.0	−1.5
gM0	3,400	+1.70	−0.8	+1.1	−2.6

Effective temperature: Kuiper, *Astrophys. J.* **88**, 464 (1938).
S4 index: computed from manufacturers' data on 1P21 photomultiplier.
Bolometric index: Kuiper, *Astrophys. J.* **88**, 452 (1938).
Photographic index: "Smithsonian Tables," 8th ed.
PbS index: computed from manufacturers' data.

6k-5. Luminance of a Blackbody and Tungsten.[1] The luminance of a blackbody and of tungsten ribbon can be represented as a function of temperature by the following formulas:

$$\log L = 7.2010 - \frac{1.1376 \times 10^4}{T} + \frac{0.00613 \times 10^8}{T^2} \qquad \text{for a blackbody}$$

$$\log L = 6.8045 - \frac{1.1236 \times 10^4}{T} + \frac{0.00538 \times 10^8}{T^2} \qquad \text{for a tungsten ribbon}$$

where L is the luminance and T is the temperature.

[1] J. C. De Vos, *Physica* **20**, 715 (1954).

TABLE 6k-16. BRIGHTNESS OF STARS AS SEEN BY VARIOUS PHOTORECEIVERS

Star	Spectral type	Visual magnitude	S4 photosurface magnitude	Lead sulfide magnitude
Sirius	A0	−1.58	−1.6	−1.6
Canopus	F0	−0.86	−0.6	−1.3
α Centauri	G0	0.06	0.8	−0.9
Vega	A0	0.14	0.1	0.1
Capella	G0	0.21	0.9	−0.8
Arcturus	K0	0.24	1.3	−1.3
Rigel	B8p	0.34	0.3	0.3
Procyon	F5	0.48	1.0	−0.2
Achernar	B5	0.60	0.5	0.7
Betelgeuse (var.)	M0	0.7 ± 0.5	1.8 ± 0.5	−1.9 ± 0.5
β Centauri	B1	0.86	0.7	1.1
Altair	A5	0.89	1.0	0.7
α Crucis	B1	1.05	0.9	1.3
Aldebaran	K5	1.06	2.1	−0.8
Pollux	K0	1.21	2.2	−0.3
Spica	B2	1.21	1.1	1.4
Antares	M0	1.22	2.3	−1.4
Fomalhaut	A3	1.29	1.4	1.2
Deneb	A2p	1.33	1.4	1.2
Regulus	B8	1.34	1.3	1.4
β Crucis	B1	1.50	1.4	1.7
Castor	A0	1.58	1.6	1.6
γ Crucis	M3	1.61	2.7	−1.4
ε Canis Majoris	B1	1.63	1.5	1.8
ε Ursa Majoris	A0p	1.68	1.7	1.7
γ Orionis	B2	1.70	1.6	1.9
λ Scorpii	B2	1.71	1.6	1.9
ε Carniae	K0	1.74	2.7	0.2
ε Orionis	B0	1.75	1.6	2.0
β Tauri	B8	1.78	1.7	1.8
β Carniae	A0	1.80	1.8	1.8
α Triang. Aust.	K2	1.88	2.9	0.2
α Persei	F5	1.90	2.4	1.2
η Ursa Majoris	B3	1.91	1.8	2.1
γ Geminorum	A0	1.93	1.9	1.9
α Ursa Majoris	K0	1.95	3.0	0.5
ε Sagitarii	A0	1.95	2.0	2.0
δ Canis Majoris	F8p	1.98	2.6	1.1
β Canis Majoris	B1	1.99	1.9	2.2

TABLE 6k-17. SOLAR SPECTRAL IRRADIANCE*

λ	P_λ	D_λ	λ	P_λ	D_λ
0.140	0.0000048	0.00050	0.420	0.1758	11.19
0.150	0.0000176	0.00059	0.425	0.1705	11.83
0.160	0.000050	0.00087	0.430	0.1651	12.45
0.170	0.00015	0.00164	0.435	0.1675	13.06
0.180	0.00035	0.00349	0.440	0.1823	13.71
0.190	0.00076	0.00760	0.445	0.1936	14.41
0.200	0.00130	0.0152	0.450	0.2020	15.14
0.205	0.00167	0.0207	0.455	0.2070	15.90
0.210	0.00269	0.0288	0.460	0.2080	16.66
0.215	0.00445	0.0420	0.465	0.2060	17.43
0.220	0.00575	0.0609	0.470	0.2045	18.19
0.225	0.00649	0.0835	0.475	0.2055	18.95
0.230	0.00667	0.1079	0.480	0.2085	19.72
0.235	0.00593	0.1312	0.485	0.1986	20.47
0.240	0.00630	0.1534	0.490	0.1959	21.20
0.245	0.00723	0.1788	0.495	0.1966	21.92
0.250	0.00704	0.2053	0.500	0.1946	22.65
0.255	0.0104	0.2375	0.505	0.1922	23.36
0.260	0.0130	0.2808	0.510	0.1882	24.07
0.265	0.0185	0.3391	0.515	0.1833	24.76
0.270	0.0232	0.4163	0.520	0.1833	25.43
0.275	0.0204	0.4960	0.525	0.1852	26.12
0.280	0.0222	0.5758	0.530	0.1842	26.80
0.285	0.0315	0.6752	0.535	0.1818	27.48
0.290	0.0482	0.8225	0.540	0.1783	28.14
0.295	0.0584	1.020	0.545	0.1754	28.80
0.300	0.0514	1.223	0.550	0.1725	29.44
0.305	0.0602	1.430	0.555	0.1720	30.08
0.310	0.0686	1.668	0.560	0.1695	30.71
0.315	0.0757	1.935	0.565	0.1700	31.34
0.320	0.0819	2.227	0.570	0.1705	31.97
0.325	0.0958	2.555	0.575	0.1710	32.60
0.330	0.1037	2.925	0.580	0.1705	33.23
0.325	0.1057	3.312	0.585	0.1700	33.86
0.340	0.1050	3.702	0.590	0.1685	34.49
0.345	0.1047	4.090	0.595	0.1665	35.11
0.350	0.1074	4.483	0.600	0.1646	35.72
0.355	0.1067	4.879	0.605	0.1626	36.33
0.360	0.1055	5.271	0.610	0.1611	36.93
0.365	0.1122	5.674	0.620	0.1576	38.11
0.370	0.1173	6.099	0.630	0.1542	39.26
0.375	0.1152	6.529	0.640	0.1517	40.39
0.380	0.1117	6.949	0.650	0.1487	41.50
0.385	0.1097	7.359	0.660	0.1468	42.00
0.390	0.1099	7.765	0.670	0.1443	43.67
0.395	0.1191	8.189	0.680	0.1418	44.73
0.400	0.1433	8.675	0.690	0.1398	45.78
0.405	0.1651	9.245	0.700	0.1369	46.80
0.410	0.1759	9.876	0.710	0.1344	47.80
0.415	0.1783	10.53	0.720	0.1314	48.79

TABLE 6k-17. SOLAR SPECTRAL IRRADIANCE* (*Continued*)

λ	P_λ	D_λ	λ	P_λ	D_λ
0.730	0.1290	49.75	3.6	0.00135	98.720
0.740	0.1260	50.69	3.7	0.00123	98.816
0.750	0.1235	51.62	3.8	0.00111	98.902
0.800	0.1107	55.95	3.9	0.00103	98.982
0.850	0.0988	59.83	4.0	0.00095	99.055
0.900	0.0889	63.30	4.1	0.00087	99.122
0.950	0.0835	66.49	4.2	0.00078	99.182
1.000	0.0746	69.42	4.3	0.00071	99.238
1.1	0.0592	74.37	4.4	0.00065	99.289
1.2	0.0484	78.35	4.5	0.00059	99.335
1.3	0.0396	81.61	4.6	0.00053	99.376
1.4	0.0336	84.32	4.7	0.00048	99.414
1.5	0.0287	86.62	4.8	0.00045	99.448
1.6	0.0244	88.59	4.9	0.00041	99.480
1.7	0.0202	90.24	5.0	0.000383	99.509
1.8	0.0159	91.58	6.0	0.000175	99.716
1.9	0.0126	92.63	7.0	0.000099	99.817
2.0	0.0103	93.48	8.0	0.000060	99.876
2.1	0.0090	94.19	9.0	0.000038	99.912
2.2	0.0079	94.82	10.0	0.000025	99.935
2.3	0.0068	95.36	11.0	0.0000170	99.951
2.4	0.0064	95.85	12.0	0.0000120	99.962
2.5	0.0054	96.287	13.0	0.0000087	99.969
2.6	0.0048	96.664	14.0	0.0000055	99.975
2.7	0.0043	97.001	15.0	0.0000049	99.9785
2.8	0.0039	97.305	16.0	0.0000038	99.9817
2.9	0.0035	97.579	17.0	0.0000031	99.9843
3.0	0.0031	97.823	18.0	0.0000024	99.9863
3.1	0.0026	98.034	19.0	0.0000020	99.9879
3.2	0.00226	98.214	20.0	0.0000016	99.9893
3.3	0.00192	98.368	λ_∞		100.0
3.4	0.00166	98.501			
3.5	0.00146	98.616			

* *NASA Rept.* X-322-68-304, August, 1968. Based on measurements on board NASA-711 *Galileo* at 33,000 ft.
λ Wavelength, μm
P_λ Solar spectral irradiance averaged over small bandwidth centered at λ, W/(cm².μm).
D_λ Percentage of the solar constant associated with wavelengths shorter than λ
Solar constant 0.013510 W/cm².

TABLE 6k-18. ENERGY DISTRIBUTION IN THE SPECTRA OF THE SELECTED STARS IN CGS UNITS*

No.	λ†	$E(\lambda)$, erg/(cm²·sec) per unit Δλ							
		β Ari	ζ Per	β Ori	ε Ori	β Tau	ε Ori	ζ Ori	α Leo
1	2	3	4	5	6	7	8	9	10
1	3,300	0.024_5	0.060_2	0.71_4	0.31_1	0.15_6	0.31_3	0.31_4	0.18_0
2	3,400	0.0244	0.0577	0.695	0.284	0.154	0.301	0.288	0.172
3	3,500	0.0243	0.0552	0.670	0.263	0.148	0.281	0.278	0.164
4	3,600	0.0244	0.0528	0.648	0.246	0.141	0.261	0.259	0.157
5	3,700	0.0251	0.0502	0.671	0.226	0.131	0.242	0.238	0.148
6	3,800	0.035_5	0.051_0	0.74_4	0.23_6	0.17_9	0.22_1	0.21_7	0.21_8
7	3,929	0.0539	0.0487	0.710	0.233	0.199	0.199	0.195	0.259
8	3,970	0.0586	0.0475	0.696	0.230	0.198	0.197	0.192	0.258
9	4,036	0.0600	0.0461	0.673	0.220	0.195	0.190	0.184	0.251
10	4,102	0.0581	0.0442	0.649	0.208	0.186	0.179	0.174	0.238
11	4,221	0.0550	0.0410	0.603	0.189	0.170	0.163	0.158	0.219
12	4,340	0.0527	0.0388	0.559	0.172	0.156	0.148	0.143	0.199
13	4,500	0.0495	0.0364	0.510	0.153	0.141	0.133	0.129	0.179
14	4,600	0.0475	0.0350	0.478	0.143	0.132	0.124	0.121	0.168
15	4,700	0.0455	0.0335	0.448	0.134	0.123	0.117	0.113	0.158
16	4,861	0.0418	0.0315	0.413	0.120	0.111	0.106	0.103	0.142
17	5,000	0.0384	0.0300	0.386	0.110	0.102	0.096_4	0.095_0	0.130
18	5,150	0.0355	0.0287	0.356	0.099_0	0.093_7	0.087_3	0.086_5	0.118
19	5,300	0.0333	0.0274	0.327	0.089_3	0.085_7	0.079_1	0.079_5	0.107
20	5,500	0.0307	0.0255	0.290	0.079_4	0.075_4	0.069_5	0.070_0	0.094_1
21	5,700	0.0283	0.0233	0.261	0.070_5	0.066_6	0.062_4	0.060_2	0.083_6
22	5,850	0.0263	0.0219	0.243	0.064_3	0.060_5	0.058_0	0.055_0	0.077_6
23	6,000	0.0246	0.0208	0.230	0.058_7	0.056_4	0.054_2	0.050_0	0.073_0
24	6,200	0.0225	0.0195	0.218	0.053_0	0.051_6	0.049_5	0.046_0	0.067_9
25	6,400	0.0209	0.0186	0.206	0.051_0	0.048_7	0.047_8	0.042_5	0.063_9
26	6,500	0.0202	0.0181	0.198	0.048_5	0.047_0	0.047_0	0.040_5	0.061_4
27	6,563	0.0198	0.0176	0.192	0.046_0	0.045_6	0.045_3	0.039_3	0.059_5
28	6,600	0.0195	0.0173	0.188	0.045_0	0.044_8	0.044_9	0.038_0	0.058_8
29	6,700	0.0189	0.0165	0.176	0.042_1	0.042_0	0.041_2	0.035_5	0.056_0
30	6,800	0.0180	0.0156	0.165	0.039_0	0.039_2	0.038_8	0.033_2	0.052_2
31	7,000	0.0160	0.0139	0.144	0.034	0.033_9	0.033_7	0.028_7	0.044_8
32	7,100	......	......	0.134	0.032	0.031_1	0.032_1	0.026_6	0.041_5
33	7,200	......	......	0.125	0.030	0.028_5	0.030_0	0.024_3	0.036_5

TABLE 6k-18. ENERGY DISTRIBUTION IN THE SPECTRA OF THE SELECTED STARS IN CGS UNITS* (*Continued*)

No.	λ†	$E(\lambda)$, erg/(cm²·sec) per unit Δλ							
		γ UMa	η UMa	α Oph	α Lyr	δ Cyg	α Aql	α Cyg	α Peg
1	2	11	12	13	14	15	16	17	18
1	3,300	0.029_4	0.16_5	0.033	0.33_9	0.024_9	0.12_3	0.10_2	0.033_4
2	3,400	0.0296	0.156	0.0344	0.320	0.0249	0.124	0.106	0.0336
3	3,500	0.0298	0.147	0.0349	0.314	0.0248	0.126	0.109	0.0340
4	3,600	0.0300	0.139	0.0354	0.308	0.0247	0.128	0.112	0.0339
5	3,700	0.0302	0.129	0.0383	0.306	0.0246	0.135	0.158	0.0342
6	3,800	0.051_8	0.14_3	0.059_0	0.50_0	0.045_2	0.19_7	0.21_7	0.055_2
7	3,929	0.0784	0.161	0.0750	0.778	0.0620	0.232	0.214	0.0874
8	3,970	0.0804	0.163	......	0.798	0.0612	.....	0.212	0.0906
9	4,036	0.0806	0.157	0.0896	0.795	0.0596	0.294	0.208	0.0873
10	4,102	0.0770	0.150	0.0866	0.765	0.0571	0.288	0.201	0.0831
11	4,221	0.0710	0.137	0.0830	0.709	0.0525	0.276	0.187	0.0770
12	4,340	0.0667	0.127	0.0796	0.655	0.0484	0.268	0.176	0.0707
13	4,500	0.0615	0.114	0.0758	0.598	0.0438	0.258	0.165	0.0642
14	4,600	0.0584	0.107	0.0739	0.564	0.0413	0.250	0.159	0.0607
15	4,700	0.0552	0.099_0	0.0712	0.531	0.0389	0.243	0.153	0.0570
16	4,861	0.0504	0.089_0	0.0650	0.484	0.0356	0.226	0.143	0.0520
17	5,000	0.0471	0.082_0	0.0609	0.449	0.0332	0.212	0.135	0.0482
18	5,150	0.0438	0.074_5	0.0571	0.413	0.0306	0.198	0.127	0.0443
19	5,300	0.0406	0.068_0	0.0535	0.382	0.0285	0.186	0.119	0.0411
20	5,500	0.0368	0.060_0	0.0491	0.345	0.0256	0.174	0.110	0.0371
21	5,700	0.0329	0.052_6	0.0453	0.313	0.0230	0.162	0.102	0.0333
22	5,850	0.0304	0.048_0	0.0425	0.290	0.0212	0.154	0.095_2	0.0388
23	6,000	0.0286	0.044_3	0.0401	0.272	0.0196	0.146	0.090_0	0.0286
24	6,200	0.0266	0.040_1	0.0379	0.248	0.0180	0.137	0.083_3	0.0261
25	6,400	0.0246	0.037_7	0.0354	0.230	0.0170	0.128	0.077_9	0.0245
26	6,500	0.0234	0.036_2	0.0336	0.220	0.0166	0.122	0.074_5	0.0234
27	6,563	0.0225	0.035_0	0.0324	0.209	0.0161	0.119	0.072_5	0.0227
28	6,600	0.0221	0.034_0	0.0318	0.204	0.0156	0.117	0.071_0	0.0221
29	6,700	0.0208	0.032_0	0.0300	0.190	0.0144	0.112	0.067_5	0.0205
30	6,800	0.0199	0.029_5	0.0282	0.178	0.0133	0.107	0.064_5	0.0190
31	7,000	......	0.026	0.0245	0.154	0.0115	0.095	0.056_6	0.0162
32	7,100	......	......	0.023	0.145	0.0105	0.090	0.052_5	0.0146
33	7,200	......	......	0.021	0.136	......	0.086	0.047_5	0.0131

* Kharitonov, A. V., *Soviet Astron.—AJ* **7**, 258 (1963).
† Wavelength in angstroms.

TABLE 6k-19. SOLAR ULTRAVIOLET FLUX INCIDENT ON EARTH'S ATMOSPHERE*

λ, Å	log f,† W/(cm²·Å)	log (f/E),‡ photons/(cm²·sec·Å)	λ, Å	log f,† W/(cm²·Å)	log (f/E),‡ photons/(cm²·sec·Å)
10	−11	4.7	900	−9.4	8.2
20	−10.2	5.8	1,000	−9.3	8.4
50	−9.6	6.8	1,100	−9.8	7.9
100	−9.5	7.2	1,200	−9.7	8.1
200	−9.4	7.6	1,400	−9.3	8.5
400	−9.8	7.5	1,600	−8.3	9.6
600	−9.8	7.7	1,800	−7.6	10.4
800	−9.8	7.8	2,000	−7.1	10.9

* Compiled by G. R. Cook, The Aerospace Corp.

† C. W. Allen, "Astrophysical Quantities," 2d ed., p. 173, Athlone Press, University of London, London, 1963.

Mean solar intensity with spectrum lines smoothed less the dominant resonance lines:

HI 1216 Å.........6×10^{-7} W/cm²
HeI 584 Å.........0.1×10^{-7} W/cm²
HeII 303 Å........0.3×10^{-7} W/cm²

‡ Photon energy $E = hc/\lambda$.

TABLE 6k-20. LABORATORY VACUUM ULTRAVIOLET SOURCES*[a]

Name	Gas	Pressure, torrs	Wave-length, Å	Excitation method	Flux, photons/(cm²·sec·Å)
			Continua		
Hopfield..................	He	50–200	600–1,000	Condensed spark	10^{10}–10^{11} [b]
Argon..................	Ar	50–200	1,060–1,500	Condensed spark	10^{10}–10^{11} [b]
Krypton..................	Kr	50–200	1,250–1,800	Condensed spark	10^{9}–10^{10} [b]
Xenon..................	Xe	50–200	1,500–1,800	Condensed spark	10^{9}–10^{10} [b]
Hydrogen..................	H_2	1–2	1,600–5,000	A-c or d-c glow	10^{7}–10^{8} [c]
Lyman, 90% He + 10% air	...	0.02–0.05	300 ~ 5,000	Condensed spark	[d]
Synchrotron..............	...	....	100–5,000	180 MeV	10^{8}–10^{9} [e]
X-ray fluorescence........	...	....	10–100	Soft X-ray tube	[f]
			Line Emission		
Hydrogen..................	H_2	1–2	850–1,600	A-c or d-c glow	~10^{11} [g]
Resonance line/He + 10%	Ar	~1	1,165, 1,236 1,470, 1,295	Microwave	10^{14} [h]
Resonance line/Ar + 10%.	H_2	~1	1,216	Microwave	10^{13} [h]
Resonance line/Ar + 10%.	O_2	~1	1,302–1,306	Microwave	10^{12} [h]
Resonance line/Ar + 10%.	N_2	~1	1,743–1,745	Microwave	10^{12} [h]
Spark spectra He + 10%..	Air	0.05	200–1,500	Condensed a-c	[i]
Hollow cathode...........	He	0.1	231–1,640	D-c glow	10^{6}–10^{7} [j]

* Compiled by G. R. Cook, The Aerospace Corp.

Notes for Table 6k-20

[a] An account of this subject may be found in J. A. R. Samson, "Vacuum Ultraviolet Spectroscopy," chap. 5, John Wiley & Sons, Inc., New York, 1967.

[b] Fluxes are approximate, and represent values that one may expect to obtain at the maximum of the continuum with a 1- or 2-m normal-incidence monochromator with a 600- or 1,200-line/mm grating. Absolute flux measurements have been reported by Metzger and Cook, *J. Opt. Soc. Am.* **55**, 516 (1965), and by R. E. Huffman, J. C. Larabee, and Y. Tanaka, *Appl. Opt.* **4**, 1581 (1965). The Ar, Kr, and Xe continua may also be excited with less intensity by microwaves. See P. G. Wilkenson and E. T. Byran, *Appl. Opt.* **4**, 581 (1965). Greater intensity may be obtained in high-energy single-flash technique. See J. A. Golden and A. L. Myerson, *J. Opt. Soc. Am.* **48**, 548 (1958).

[c] At about 1,850 Å. See D. M. Packer and C. Lock, *J. Opt. Soc. Am.* **41**, 699 (1951).

[d] This source requires current densities of 30,000 $Å/cm^2$ or more in the light-source capillary tubes. Flash tubes have been designed which produce a well-developed photographic spectrum after two or three flashes. See W. R. S. Garton, *J. Sci. Instr.* **36**, 11 (1959), and M. Nakamura, *Sci. Light (Tokyo)* **16**, 179 (1967). For wavelengths shorter than about 1,000 Å the continuum contains numerous emission lines.

[e] These values are for the NBS 180-MeV, $R = 83$ cm, electron synchrotron at a distance of about 2 m along the tangent to the orbit before entering the spectrograph with $\lambda = 304$ Å. See K. Codling and P. Madden, *J. Appl. Phys.* **36**, 380 (1956). For 6-GeV electrons in a 31.7-m orbit see R. Haensel and C. Kunz, *Z. Angew. Phys.* **23**, 276 (1967). The wavelength of the maximum of the continuum decreases according to $\lambda = 2.35R/E^3$, where λ is in Å, R is in meters, and E in GeV. For 1 GeV and $R = 31.7$ m, the maximum of the continuum is at about 75 Å.

[f] Fluorescence in the 10- to 100-Å region is detected with proportional counters containing P-10 or methane gas. For analysis of the light elements Mg to Be typical counting rates vary from 30 to 7,200 per sec, with peak to background ratios between 4 and 55. See B. L. Henke in "Advances in X-ray Analysis," vol. 8, p. 269, Plenum Press, Plenum Publishing Corporation, New York, 1965.

[g] This is the flux observed at $\lambda = 1215.6$ with a 1-m monochromator with the light source operated 400 mA. See D. M. Packer and C. Lock, *J. Opt. Soc. Am.* **41**, 699 (1951). A wavelength table of the H_2 and many line spectra with relative intensities has been prepared by K. E. Schubert and R. D. Hudson, ATN-64 (9233)-2, October, 1963, The Aerospace Corp., P. O. Box 95085, Los Angeles, Calif. 90045.

[h] About 50-W microwave power at 2450 MH coupled to the gas in a 13-mm OD capillary. See H. Okabe, *J. Opt. Soc. Am.* **54**, 478 (1964). A table of wavelengths of emission lines from neutral and ionized atoms in the 6 to 2,000 Å range has been prepared by R. L. Kelly, UCRL 5612, University of California, Lawrence Radiation Laboratory, Livermore, Calif. For each line there are one or more references to the original literature.

[i] Current densities less than for the Lyman discharge allow pulse rates in the 50 to 400 per sec region. These rates are convenient for photoelectric detection. Details of this source have been published by P. Lee and G. E. Weissler, *J. Opt. Soc. Am.* **42**, 80 (1952).

[j] These are photon fluxes at the entrance slit of a 1-m grazing incident monochromator necessary to produce an output current of 10^{-9} amp from a Bendix magnetic-type multiplier. See E. Hinnov and F. Hofmann, *J. Opt. Soc. Am.* **53**, 1259 (1963).