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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Specification for SOLAR CONSTANT AND AIR MASS ZERO SOLAR SPECTRAL IRRADIANCE¹

This Standard is issued under the fixed designation E 490; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This specification defines the solar constant and the zero air mass solar spectral irradiance for use in thermal analysis, thermal balance testing, and other tests of spacecraft and spacecraft components and materials.

1.2 This specification is based upon data from experimental measurements made from high-altitude aircraft, balloons, spacecraft, and the earth's surface. The stated accuracies are based on the estimated accuracies of the measurements, calibrations, and radiometric scales.

2. Applicable Documents

2.1 ASTM Standards:

E 349 Definitions of Terms Relating to Space Simulation²

3. Definitions of Terms

3.1 *air mass* (optical air mass) (AM)—the ratio of the path length or radiation through the atmosphere (l_m) at any given angle, Z deg, to the sea level path length toward the zenith (l_z).

$$AM = l_m/l_z \cong \sec Z, \text{ for } Z \leq 62 \text{ deg}$$

Symbol: AM1 (air mass one), AM2 (air mass two)

3.2 *air mass zero* (AM0)—the absence of atmospheric attenuation of the solar irradiance at one astronomical unit from the sun.

3.3 *astronomical unit* (AU)—a unit of length defined as the mean distance between the earth and the sun that is, $149\,597\,890 \pm 500$ km).

3.4 *irradiance at a point on a surface* (E)—quotient of the radiant flux incident on an element of the surface containing the point, by the area of that element, measured in $W \cdot m^{-2}$.

3.5 *irradiance, spectral* (E_λ)—the irradiance per unit wavelength interval at a specific wavelength, or as a function of wavelength measured in $W \cdot m^{-2} \cdot \mu m^{-1}$.

3.6 *integrated irradiance*—spectral irradiance integrated over a specific wavelength interval from λ_1 to λ_2 , measured in $W \cdot m^{-2}$.

$$\text{Symbol: } E_{\lambda_1-\lambda_2} = \int_{\lambda_1}^{\lambda_2} E_\lambda d\lambda$$

3.7 Additional definitions will be found in Definitions E 349.

4. Solar Constant

4.1 The solar constant, based on the average of the values shown in Table 1, is $1353 W \cdot m^{-2}$. The estimated error is $\pm 21 W \cdot m^{-2}$.

4.2 Table 2 summarizes the results in different units, and Table 3 presents the total solar irradiance at various planetary distances from the sun.

5. Solar Spectral Irradiance (Air Mass Zero)

5.1 The zero air mass solar spectral irradiance is based on data from the NASA 711 research aircraft experiments (1,2,3)³ (see Table 4) with additions and revisions based on other recent measurements (16). Previously compiled solar spectral irradiances were based on ground-based measurements (17 to 25) and some measurements from rockets (26). Spectral irradiance data from the NASA Ames Research Center (27) were not included because of

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³The boldface numbers in parentheses refer to the list of references at the end of this specification.

calibration uncertainties. Further discussion on the methods of calculation and historical information can be found in Refs (3,16,28 to 31).

5.2 Table 5 presents the solar spectral irradiance in tabular form for the range from 0.115 to 1000 μm . The first column gives the wavelength (λ) in μm ; the second gives the spectral irradiance (E_λ) at λ in $\text{W}\cdot\text{m}^{-2}\cdot\mu\text{m}^{-1}$; the third gives the total irradiance for the range from 0 to λ ($E_{0-\lambda}$) in $\text{W}\cdot\text{m}^{-2}$; and the fourth gives the percentage of the solar constant associated with wavelengths shorter than λ ($D_{0-\lambda}$).

5.3 Table 6 presents an abridged version of Table 5. Figure 1 plots the Standard Solar Spectral Irradiance.

5.4 The irradiance in the range from 0 to

0.115 μm (nearly $0.0025 \text{ W}\cdot\text{m}^{-2}$) is based on Hinteregger's results (32). In the 0.14 to 0.20- μm range, the values are based on Naval Research Laboratory data (17, 26), which have been adjusted downward because of data by Heath (33) and Parkinson and Reeves (34). In the range from 0.20 to 0.30 μm , the values of the Goddard Space Flight Center curve have been retained because of confirming Nimbus satellite data (33). The Epply-JPL data were used for revision in the range from 0.3 to 0.7 μm (9 to 13). The 20 to 1000- μm range (9 to 13, 16) irradiances were computed from the combined data on the brightness temperature of the sun from many different authors as quoted by Shimabukoro and Stacey (35).

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TABLE 1 Solar Constant

Platform	Detector	Year	Solar Constant, W·m ⁻²	Ref
NASA 711 aircraft	Hy-Cal pyrheliometer	1967	1358	1,2,3
NASA 711 aircraft	Ångström 7635	1967	1349	1,2,3
NASA 711 aircraft	Ångström 6618	1967	1343	1,2,3
NASA 711 aircraft	cone radiometer	1967	1358	1,2,3
Soviet balloon	U. of Leningrad actinometer	1961-1968	1353	4,5
U. of Denver balloon	Eppley pyrheliometer	1969	1338	6,7
Eppley-JPL high-altitude aircraft	Eppley pyrheliometer	1966-1968	1360	8 to 13
Mariner VI and VIII spacecraft	cavity radiometer	1969	1353	14
JPL balloon	cavity radiometer	1968-1969	1368	15
Average estimated error			1353 ± 21	

TABLE 2 Solar Constant Conversion Factors

Solar constant	= 1353 W·m ⁻² (±21 W·m ⁻²) [preferred unit]
	= 0.1353 W·cm ⁻²
	= 135.3 mW·cm ⁻²
	= 1.353 × 10 ⁶ erg·cm ⁻² ·s ⁻¹
	= 125.7 W·ft ⁻²
	= 1.940 cal·cm ⁻² ·min ⁻¹
	(±0.03 cal·cm ⁻² ·min ⁻¹)
	= 0.0323 cal·cm ⁻² ·s ⁻¹
	= 429.2 Btu·ft ⁻² ·h ⁻¹
	= 0.119 Btu·ft ⁻² ·s ⁻¹
	= 1.937 Langleys·min ⁻¹

The calorie is the thermochemical caloric-gram and is defined as 4.1840 absolute joules. The Btu is the thermochemical British thermal unit and is defined by the relationship: 1 Btu (thermochemical)/(°F × lb) = 1 cal·g (thermochemical)/(°C × g).

The Langley, however, is defined in terms of the older thermal unit the caloric-g (mean), that is, 1 Langley = 1 cal·g (mean)·cm⁻²; 1 cal·g (mean) = 4.19002 J.

TABLE 3 Solar Irradiance at the Planets

Planet	Solar Irradiance, W·m ⁻²		
	Mean	Perihelion	Aphelion
Mercury	9029.0	14309.0 ¹	6211.0
Venus	2586.0	2621.0	2551.0
Earth	1353.0	1399.0	1309.0
Mars	583.0	709.0	487.0
Jupiter	50.0	55.2	45.5
Saturn	14.9	16.6	13.4
Uranus	3.68	4.07	3.34
Neptune	1.496	1.500	1.493
Pluto	0.870	1.556	0.555

TABLE 4 Spectral Irradiance Instruments On Board the NASA 711 Galileo Research Aircraft, Used for Obtaining the GSFC Curve of Solar Spectral Irradiance (Refs 1, 2, 3)

Instrument	Energy Detector	Type of Instrument	Aircraft Window Material	Wavelength Range, μm
Perkin-Elmer monochromator	IP28 tube, thermocouple	LiF prism	sapphire	0.3-0.7 0.7-4
Leiss monochromator	EMI 9558QA, PbS cell	quartz double prism	Dynasil quartz	0.3-0.7 0.7-1.6
Filter radiometer	phototube	dielectric thin films	Dynasil quartz	0.3-1.2
P-4 interferometer	IP28 or R 136 PbS cell	Soleil prism	Infrasil quartz	0.3-0.7 0.7-2.5
I-4 interferometer	thermistor bolometer	Michelson mirror	Irtran 4	2.6-15

TABLE 5 Solar Spectral Irradiance—Standard Curve

λ = wavelength, μm .
 E_λ = solar spectral irradiance averaged over small bandwidth centered at λ , $\text{W}\cdot\text{m}^{-2}\cdot\mu\text{m}^{-1}$
 $E_{0-\lambda}$ = integrated solar irradiance in the wavelength range 0 to λ , in $\text{W}\cdot\text{m}^{-2}$,
 $D_{0-\lambda}$ = percentage of solar constant associated with wavelengths shorter than λ , and
 solar constant = $1353 \text{ W}\cdot\text{m}^{-2}$
 Note.—Lines indicate change in wavelength interval of integration.

λ	E_λ	$E_{0-\lambda}$	$D_{0-\lambda}$	λ	E_λ	$E_{0-\lambda}$	$D_{0-\lambda}$	λ	E_λ	$E_{0-\lambda}$	$D_{0-\lambda}$
.115	.007	.0025	.0001	.510	1.882	324.926	24.015	1.55	267	1186.109	87.665
.120	.900	.0048	.0002	.515	1.873	334.214	24.701	1.60	245	1198.909	88.611
.125	.007	.0070	.0005	.520	1.823	343.379	25.379	1.65	223	1210.609	89.475
.130	.007	.0071	.0005	.525	1.852	352.591	26.059	1.70	202	1221.234	90.261
.140	.030	.0073	.0005	.520	1.842	351.826	26.742	1.75	180	1230.784	90.967
.150	.070	.0078	.0005	.525	1.818	370.976	27.418	1.80	159	1239.259	91.593
.160	.230	.0093	.0006	.540	1.783	378.979	28.084	1.85	142	1246.784	92.149
.170	.630	.0136	.0010	.545	1.754	388.821	28.737	1.90	126	1253.484	92.644
.180	1.250	.0230	.0016	.550	1.725	397.519	29.390	1.95	114	1259.484	93.088
.190	2.710	.0428	.0031	.555	1.720	406.131	30.017	2.00	103	1264.909	93.489
.200	10.7	.1098	.0081	.560	1.695	414.669	30.648	2.1	90	1274.559	94.2024
.210	22.9	.2778	.0205	.565	1.705	423.169	31.276	2.2	79	1283.009	94.8269
.220	57.5	.6798	.0502	.570	1.712	431.711	31.907	2.3	69	1290.409	95.3739
.225	64.9	.9858	.0728	.575	1.719	440.289	32.541	2.4	62	1296.959	95.8580
.230	66.7	1.3148	.0971	.580	1.715	448.874	33.176	2.5	55	1302.809	96.2903
.235	59.3	1.6298	.1204	.585	1.712	457.441	33.809	2.6	48	1307.959	96.6710
.240	63.0	1.9356	.1430	.590	1.700	465.971	34.439	2.7	43	1312.509	97.0073
.245	72.3	2.2738	.1680	.595	1.682	474.426	35.064	2.8	39	1316.609	97.3103
.250	70.4	2.6306	.1944	.600	1.666	482.796	35.683	2.9	35	1320.309	97.5838
.255	104.0	3.0666	.2266	.605	1.647	491.079	36.295	3.0	31	1323.609	97.8277
.260	130	3.6516	.269	.61	1.635	499.284	36.902	3.1	28.0	1326.459	98.0383
.265	185	4.4391	.328	.62	1.602	515.469	38.098	3.2	22.6	1328.889	98.2179
.270	232	5.4816	.405	.63	1.570	531.329	39.270	3.3	19.2	1330.979	98.3724
.275	204	6.5716	.485	.64	1.544	546.899	40.421	3.4	16.4	1332.769	98.5047
.280	222	7.6366	.564	.65	1.511	562.174	41.550	3.5	14.6	1334.329	98.6200
.285	315	8.9791	.663	.66	1.486	577.159	42.657	3.6	13.5	1335.734	98.7238
.290	482	10.9718	.810	.67	1.456	591.869	43.744	3.7	12.3	1337.024	98.8192
.295	584	13.6366	1.007	.68	1.427	606.284	44.810	3.8	11.1	1338.194	98.9056
.300	514	16.3816	1.210	.69	1.402	620.429	45.855	3.9	10.3	1339.264	98.9847
.305	603	19.1741	1.417	.70	1.369	634.284	46.879	4.0	9.5	1340.254	99.0579
.310	689	22.4041	1.655	.71	1.344	647.849	47.882	4.1	8.70	1341.1641	99.12521
.315	764	26.0366	1.924	.72	1.314	661.139	48.864	4.2	7.80	1341.9891	99.18618
.320	830	30.0216	2.218	.73	1.290	674.159	49.826	4.3	7.10	1342.7341	99.24124
.325	975	34.5341	2.552	.74	1.260	686.909	50.769	4.4	6.50	1343.4141	99.29150
.330	1059	39.6191	2.928	.75	1.235	699.384	51.691	4.5	5.92	1344.0351	99.33740
.335	1081	44.9691	3.323	.76	1.211	711.614	52.595	4.6	5.35	1344.5986	99.37905
.340	1074	50.3566	3.721	.77	1.185	723.594	53.480	4.7	4.86	1345.1091	99.41678
.345	1069	55.7141	4.117	.78	1.159	735.314	54.346	4.8	4.47	1345.5757	99.45127
.350	1093	61.1191	4.517	.79	1.134	746.779	55.194	4.9	4.11	1346.0049	99.48299
.355	1083	66.5591	4.919	.80	1.109	757.994	56.023	5.0	3.79	1346.3999	99.51219
.360	1068	71.9366	5.316	.81	1.085	768.966	56.834	6	1.8200	1349.2049	99.71950
.365	1132	77.4366	5.723	.82	1.060	779.694	57.627	7	.9900	1350.6099	99.82335
.370	1181	83.2191	6.150	.83	1.036	790.174	58.401	8	.5850	1351.3974	99.88155
.375	1157	89.0641	6.582	.84	1.013	800.419	59.158	9	.3670	1351.8734	99.91673
.380	1120	94.7566	7.003	.85	990	810.434	59.899	10	.2410	1352.1774	99.93920
.385	1098	100.3016	7.413	.86	968	820.224	60.622	11	.1650	1352.3804	99.95420
.390	1098	105.7916	7.819	.87	947	829.799	61.330	12	.1170	1352.5214	99.96462
.395	1189	111.5091	8.241	.88	926	839.164	62.022	13	.0851	1352.6224	99.97209
.400	1429	118.0541	8.725	.89	908	848.334	62.700	14	.0634	1352.6967	99.97758
.405	1644	125.7366	9.293	.90	891	857.329	63.365	15	.0481	1352.7524	99.98170
.410	1751	134.224	9.920	.91	880	866.184	64.019	16	.037100	1352.7950	99.98485
.415	1774	143.036	10.571	.92	869	874.929	64.665	17	.029100	1352.8281	99.98730
.420	1747	151.839	11.222	.93	858	883.564	65.304	18	.023100	1352.8542	99.98923
.425	1693	160.439	11.858	.94	847	892.089	65.934	19	.018001	1352.8751	99.99077
.430	1639	168.769	12.473	.95	837	900.509	66.556	20	.015200	1352.8920	99.99202
.435	1583	177.024	13.083	.96	820	908.794	67.168	25	.006170	1352.9454	99.99595
.440	1510	185.706	13.725	.97	803	916.909	67.768	30	.002971	1352.9683	99.99765
.445	1422	195.036	14.415	.98	785	924.849	68.355	35	.001600	1352.9797	99.99850
.450	2006	204.866	15.140	.99	767	932.609	68.928	40	.000942	1352.9860	99.99947
.455	2057	215.014	15.891	1.00	748	940.184	69.488	50	.000391	1352.9927	99.99946
.460	2066	225.321	16.653	1.05	668	975.584	72.105	60	.00019700	1352.9956	99.99967
.465	2048	235.605	17.413	1.10	593	1007.109	74.435	80	.00006160	1352.9981	99.99986
.470	2033	245.809	18.167	1.15	535	1035.309	76.519	100	.00002570	1352.9990	99.99992
.475	2044	256.001	18.921	1.20	485	1060.809	78.404	120	.00001260	1352.9994	99.99995
.480	2074	266.296	19.681	1.25	438	1083.884	80.109	150	.00000523	1352.9997	99.99997
.485	1976	276.421	20.430	1.30	397	1104.759	81.652	200	.00000165	1352.9998	99.99999
.490	1950	286.236	21.155	1.35	358	1123.634	83.047	250	.00000070	1352.9999	99.99999
.495	1960	296.011	21.878	1.40	337	1141.009	84.331	300	.00000034	1352.9999	99.99999
.500	1942	305.766	22.599	1.45	312	1157.234	85.530	400	.00000011	1352.9999	99.99999
.505	1928	315.421	23.312	1.50	288	1172.234	86.639	1000	.00000000	1353.0000	100.00000

TABLE 6 Solar Spectral Irradiance—Standard Curve, Abridged Version

λ = wavelength, μm .
 E_{λ} = solar spectral irradiance averaged over small bandwidth centered at λ , $\text{W} \cdot \text{m}^{-2} \cdot \mu\text{m}^{-1}$.
 $D_{0-\lambda}$ = percentage of the solar constant associated with wavelengths shorter than λ , and
 solar constant = $1353 \text{ W} \cdot \text{m}^{-2}$

λ	E_{λ}	$D_{0-\lambda}$	λ	E_{λ}	$D_{0-\lambda}$	λ	E_{λ}	$D_{0-\lambda}$
0.115	.007	1×10^{-4}	0.43	1639	12.47	0.90	891	63.37
0.14	.03	5×10^{-4}	0.44	1810	13.73	1.00	748	69.49
0.16	.23	6×10^{-4}	0.45	2006	15.14	1.2	485	70.40
0.18	1.25	1.6×10^{-3}	0.46	2066	16.65	1.4	337	84.33
0.20	10.7	8.1×10^{-3}	0.47	2033	18.17	1.6	245	88.61
0.22	57.5	0.05	0.48	2074	19.68	1.8	159	91.59
0.23	66.7	0.10	0.49	1950	21.15	2.0	103	93.49
0.24	63.0	0.14	0.50	1942	22.60	2.2	79	94.83
0.25	70.9	0.19	0.51	1882	24.01	2.4	62	95.86
0.26	130	0.27	0.52	1833	25.38	2.6	48	96.67
0.27	232	0.41	0.53	1842	26.74	2.8	39	97.31
0.28	222	0.56	0.54	1783	28.08	3.0	31	97.83
0.29	482	0.81	0.55	1725	29.38	3.2	22.6	98.22
0.30	514	1.21	0.56	1695	30.65	3.4	16.6	98.50
0.31	689	1.66	0.57	1712	31.91	3.6	13.5	98.72
0.32	830	2.22	0.58	1715	33.18	3.8	11.1	98.91
0.33	1059	2.93	0.59	1700	34.44	4.0	9.5	99.06
0.34	1074	3.72	0.60	1666	35.68	4.5	5.9	99.34
0.35	1093	4.52	0.62	1602	38.10	5.0	3.8	99.51
0.36	1068	5.32	0.64	1544	40.42	6.0	1.8	99.72
0.37	1181	6.15	0.66	1486	42.66	7.0	1.0	99.82
0.38	1120	7.00	0.68	1427	44.81	8.0	.59	99.88
0.39	1098	7.82	0.70	1369	46.88	10.0	.24	99.94
0.40	1429	8.73	0.72	1314	48.86	15.0	4.8×10^{-2}	99.98
0.41	1751	9.92	0.75	1235	51.69	20.0	1.5×10^{-2}	99.99
0.42	1747	11.22	0.80	1109	56.02	50.0	3.9×10^{-4}	100.00

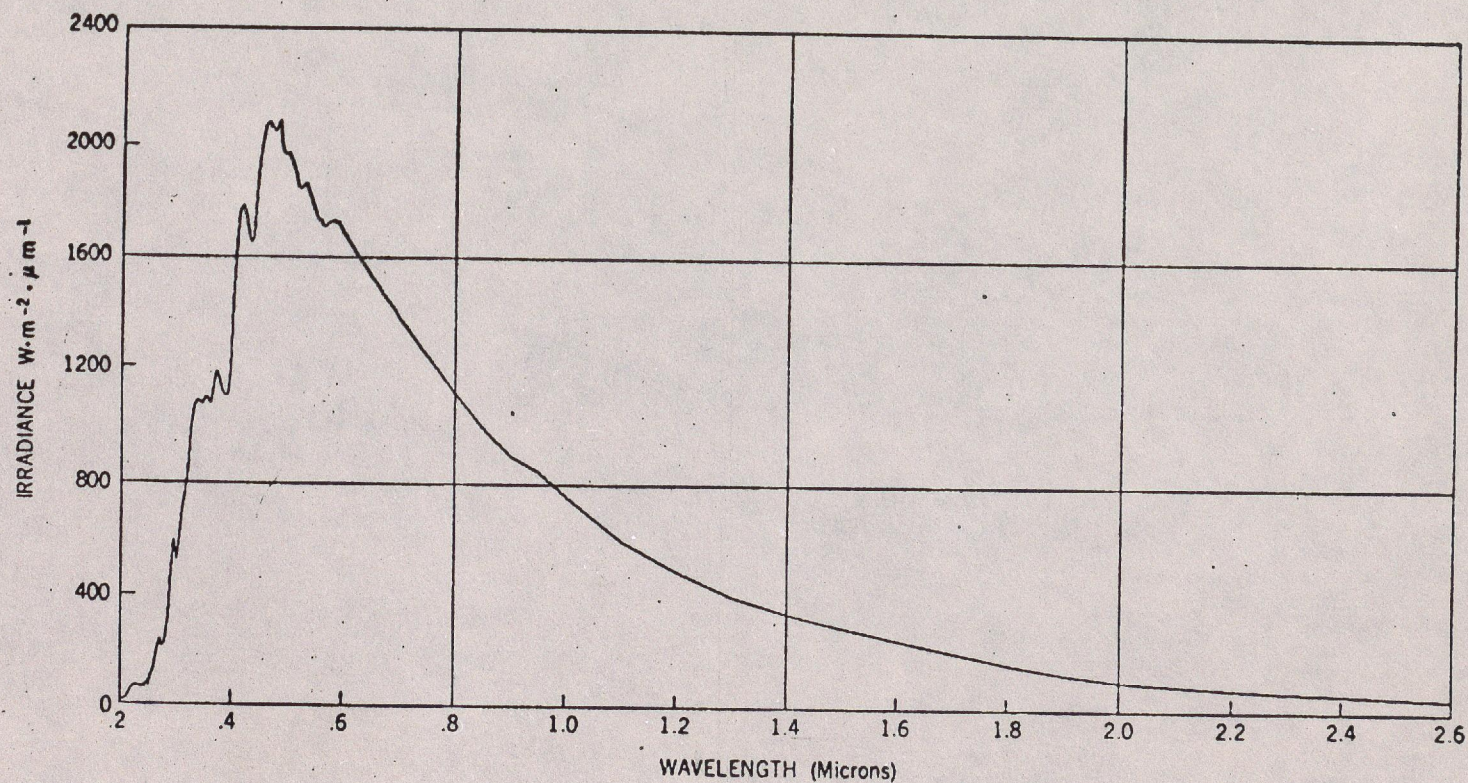


FIG. 1 Solar Spectral Irradiance.

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