

Stefan Boltzmann Lampe 1008523

Bedienungsanleitung

02/24 NF/ALF/UD



1. Sicherheitshinweise

Die Stefan-Boltzmann-Lampe entspricht den Sicherheitsbestimmungen für elektrische Mess-, Steuer-, Regel- und Laborgeräte nach DIN EN 61010 Teil 1. Sie ist für den Betrieb in trockenen Räumen vorgesehen, die für elektrische Betriebsmittel geeignet sind.

Bei bestimmungsgemäßem Gebrauch ist der sichere Betrieb der Ausstattung gewährleistet. Die Sicherheit ist jedoch nicht garantiert, wenn die Geräte unsachgemäß bedient oder unachtsam behandelt werden.

Achtung: Die Lampe wird im Betrieb sehr heiß. Bei Berührung besteht Verbrennungsgefahr! Zudem können sich Fettrückstände einbrennen.

- Lampe nicht mit den Fingern anfassen.
- Nach Beendigung des Experiments Lampe abkühlen lassen.

Hinweis:

Bei Anschlussspannungen über 13 V wird der Glühfaden zerstört.

- Niemals eine höhere Spannung als 13 V an die beiden 4-mm-Buchsen anschließen.

2. Beschreibung

Die Stefan-Boltzmann-Lampe ist eine Hochtemperaturquelle mit einem Wolfram-Glühfaden. Sie dient zur Erzeugung von Wärmestrahlung und zur Untersuchung deren Temperaturabhängigkeit bzw. zur Bestätigung des Stefan-Boltzmann-Gesetzes in der Form

$$P = \varepsilon \cdot \sigma \cdot A \cdot T^4.$$

Hierbei ist P die abgestrahlte Leistung, T die absolute Temperatur des Glühfadens, A dessen Oberfläche, σ die Stefan-Boltzmann-Konstante und ε eine dimensionslose Konstante zwischen 0 und 1. Die Temperatur der Lampe wird dabei aus dem Widerstand der Heizwendel berechnet.

Der Glühfaden stellt in sehr guter Näherung eine punktförmige Strahlungsquelle dar und ist damit auch für die Untersuchung des Gesetzes vom reziproken Abstandsquadrat geeignet.

3. Lieferumfang

1 Stefan-Boltzmann-Lampe
1 Stativstab, 130 mm lang

4. Technische Daten

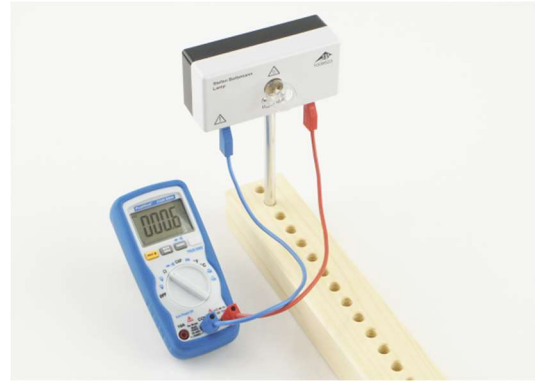
Nennspannung:	12 V DC
Nennstrom:	1,75 A
Nennleistung:	21 W
Max. Betriebswerte:	13 V DC / 2 A
Maximale Temperatur des Glühfadens:	3600 K
Abstand Glühfaden zum Stativstab:	25 mm

5. Experimentierbeispiel

Zusätzlich erforderlich:

1 Thermosäule	1000824
1 DC-Netzgerät 20 V, 5 A (@230V) oder	1003312
1 DC-Netzgerät 20 V, 5 A (@115V)	1003311
1 Digital-Multimeter P3340	1002785
2 Digital-Multimeter P1035	1002781
2 Tonnenfüße, 1000 g	1002834
1 Sicherheitsexperimentierkabel (15 Stk.)	1002843

5.1 Messung des Glühfadenwiderstands bei Raumtemperatur



- Je eine Messleitung in die COM- und in die V Ω mA-Buchse des Digital-Multimeters P3340 (1002785) stecken und kurzschließen.
- Ω -Bereich auswählen, Null-Anzeige abwarten, anschließend kurz die Taste REL drücken.
- Kurzschluss der Messleitungen öffnen und die Leitungen in die beiden Buchsen der Stefan-Boltzmann Lampe stecken.
- Widerstandswert R_{ref} ablesen und notieren (Tab. 1).
- Messleitungen entfernen.
- Mit dem Thermofühler des Multimeters in der Nähe der Lampe die Umgebungstemperatur T_{ref} in Kelvin messen und notieren (Tab. 1).

Tab. 1: Bei Raumtemperatur gemessener Wert des Glühfadenwiderstandes

R_{ref}	0,541 Ω
T_{ref}	297 K

5.2 Messung der Strahlungsintensität in Abhängigkeit von der ermittelten Temperatur des Glühfadens



- Die Thermosäule an das Digital-Multimeter P3340 (1002785) anschließen.
- Stefan-Boltzmann-Lampe vor der Thermosäule aufbauen und mit dem DC-Netzgerät und den beiden Digital-Multimetern P1035 (1002781) zusammenschalten.
- Spannung U um jeweils 1 V steigend bis max. 12 V einstellen, Lampenspannung U , Lampenstrom I , und mit der Thermosäule die abgestrahlte Intensität Φ messen (5.3, Tab. 2).

5.3 Auswertung

- $R = U/I$ berechnen (Tab. 2).
- Mit den ermittelten Werten T_{ref} , R_{ref} , R und dem Widerstands-Temperaturkoeffizienten $\alpha = 4,4 \cdot 10^{-3} \text{ K}^{-1}$ für Wolfram lässt sich die Temperatur des Glühfadens nach der Formel

$$T = \left(\frac{R - R_{\text{ref}}}{\alpha \cdot R_{\text{ref}}} \right) + T_{\text{ref}}$$

berechnen (Tab. 2).

Eine alternative Möglichkeit zur Bestimmung der Temperatur T des Glühfadens ist, den Quotienten R / R_{ref} zu berechnen und daraus mit Hilfe von Fig. 2 bzw. Tabelle 3 im Anhang die Temperatur zu ermitteln.

Hinweis: In Tabelle 3 ist der Quotient R / R_{ref} sowohl für $T_{\text{ref}} = 300 \text{ K}$ als auch für $T_{\text{ref}} = 290 \text{ K}$ angegeben. Für eine genauere Auswertung kann zwischen diesen Werten interpoliert werden, um die tatsächliche Raumtemperatur zu berücksichtigen.

- Φ in Abhängigkeit von T^4 darstellen (Fig 3).

Tab. 2: Aus den gemessenen Werten für die Lampenspannung U und den Lampenstrom I berechneten Werte für den Widerstand R und die Temperatur T des Glühfadens sowie die mit der Thermosäule gemessene abgestrahlte Intensität Φ .

U / V	I / A	R / Ω	T / K	Φ / V
0,00369	0,006	0,615	328	0
1,0502	0,554	1,896	854	0,0001
2,033	0,706	2,879	1259	0,0004
3,012	0,837	3,599	1554	0,0011
4,003	0,958	4,178	1792	0,0019
5,012	1,071	4,679	1998	0,0029
6,017	1,174	5,125	2181	0,0042
7,074	1,276	5,5434	2353	0,0058
8,028	1,362	5,894	2497	0,0072
9,011	1,446	6,232	2636	0,0088
10,088	1,534	6,576	2777	0,0106
11,02	1,607	6,8575	2893	0,0125
11,685	1,68	6,955	2933	0,0145

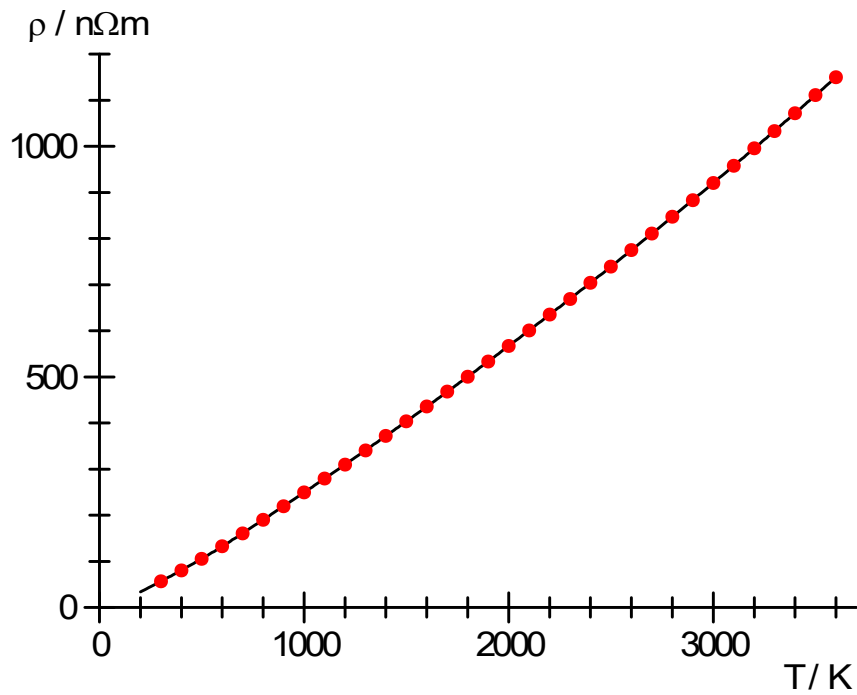


Fig. 1: Spezifischer Widerstand ρ von Wolfram in Abhängigkeit von der absoluten Temperatur T (vgl. Tab. 3). Kurve angepasst an Messwerte von Zerda, T.W., Texas Christian University, 2001

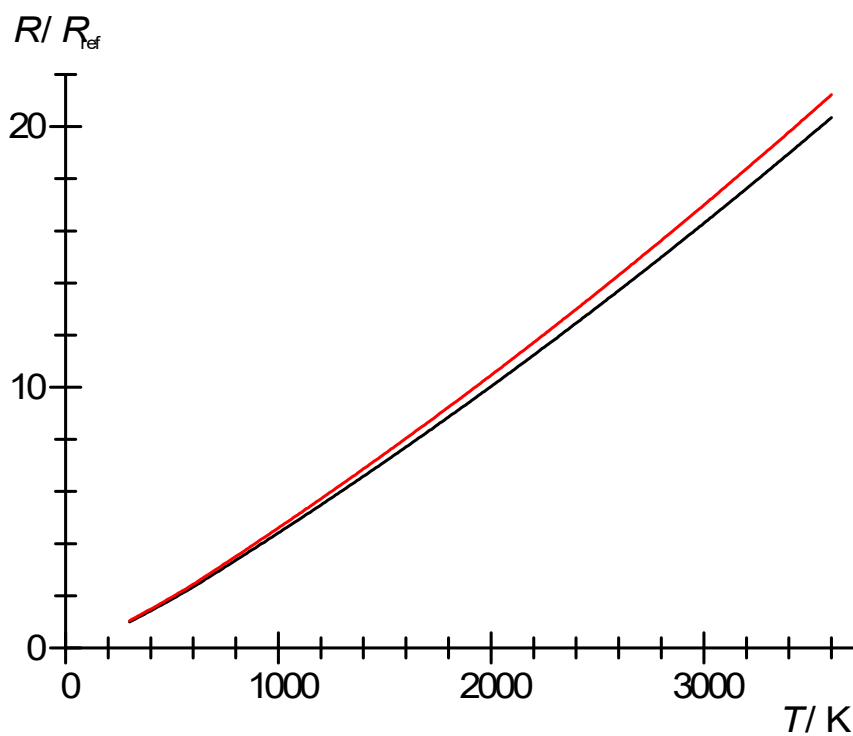


Fig. 2: Aus den in Fig. 1 dargestellten Werten berechnete Widerstandsverhältnisse $R(T)/R_{300\text{K}}$ (schwarz) bzw. $R(T)/R_{290\text{K}}$ (rot) (vgl. Tab. 3)

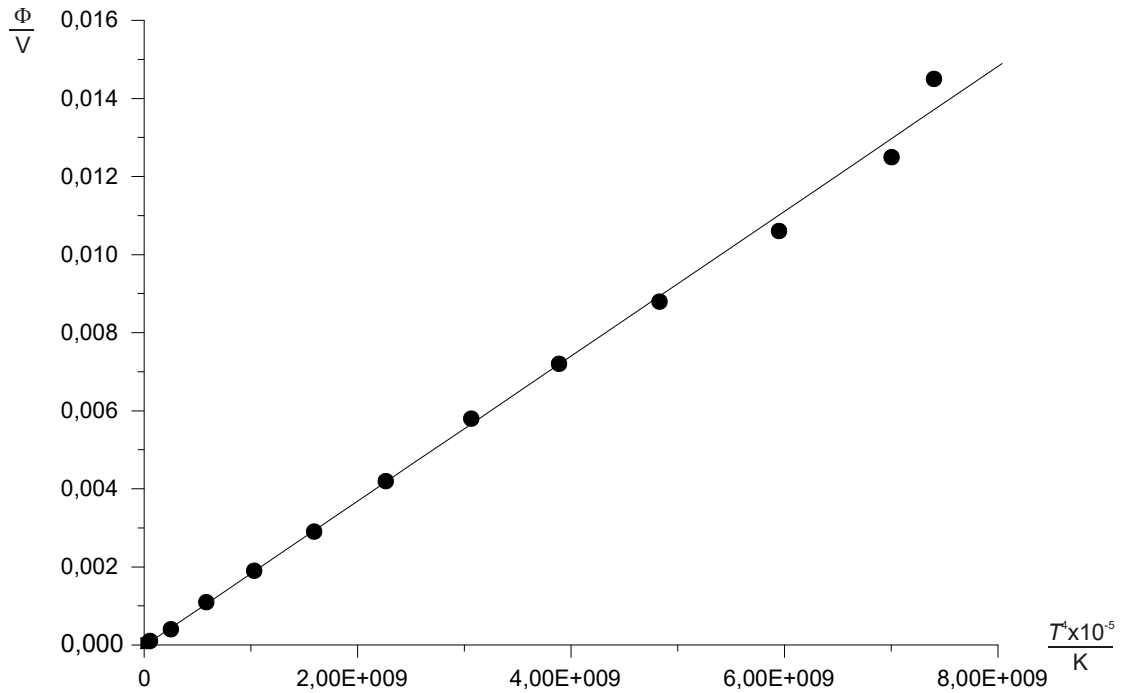


Fig. 3: Strahlungsintensität Φ in Abhängigkeit der Temperatur T

6. Lampenwechsel

Zum Lampenwechsel sind folgende Werkzeuge zusätzlich erforderlich:

1 Lampe 12 V / 21 W, Sockel BA15S

1 Schraubenzieher

1 Sandpapier

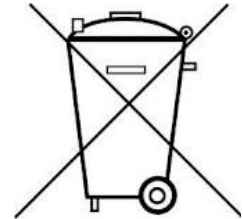
1 Lötkolben

Lötzinn

- Rückschale des Gehäuses abschrauben.
- Lampe ablöten.
- Neue Lampe an den Stellen, an denen der Draht angelötet wird, mit Sandpapier anschleifen und verzinnen.
- Lampe einsetzen und anlöten.
- Lampe mit 12 V testen.
- Gehäuse wieder zuschrauben.

7. Entsorgung

- Die Verpackung ist bei den örtlichen Recyclingstellen zu entsorgen.
- Sofern das Gerät selbst verschrottet werden soll, so gehört dieses nicht in den normalen Hausmüll. Es sind die lokalen Vorschriften zur Entsorgung von Elektroschrott einzuhalten.



8. Anhang

Tab. 3: Spezifischer Widerstand ρ von Wolfram in Abhängigkeit von der absoluten Temperatur T und daraus berechnete Widerstandsverhältnisse $R(T) / R_{300\text{K}}$ bzw. $R(T) / R_{290\text{K}}$ (vgl. Fig. 1 und Fig. 2)

$\frac{T}{\text{K}}$	ρ n Ωm	$\frac{R(T)}{R_{300\text{K}}}$	$\frac{R(T)}{R_{290\text{K}}}$	$\frac{T}{\text{K}}$	ρ n Ωm	$\frac{R(T)}{R_{300\text{K}}}$	$\frac{R(T)}{R_{290\text{K}}}$	$\frac{T}{\text{K}}$	ρ n Ωm	$\frac{R(T)}{R_{300\text{K}}}$	$\frac{R(T)}{R_{290\text{K}}}$	$\frac{T}{\text{K}}$	ρ n Ωm	$\frac{R(T)}{R_{300\text{K}}}$	$\frac{R(T)}{R_{290\text{K}}}$
290	54,17	1,000		710	163,86	2,900	3,025	1130	288,49	5,106	5,325	1550	419,46	7,424	7,743
300	56,50	1,000	1,043	720	166,76	2,951	3,078	1140	291,53	5,160	5,381	1560	422,65	7,481	7,802
310	58,84	1,041	1,086	730	169,65	3,003	3,132	1150	294,58	5,214	5,438	1570	425,85	7,537	7,861
320	61,19	1,083	1,130	740	172,55	3,054	3,185	1160	297,63	5,268	5,494	1580	429,06	7,594	7,920

330	63,56	1,125	1,173	750	175,46	3,105	3,239	1170	300,69	5,322	5,550	1590	432,26	7,651	7,979
340	65,93	1,167	1,217	760	178,37	3,157	3,292	1180	303,75	5,376	5,607	1600	435,47	7,707	8,038
350	68,33	1,209	1,261	770	181,28	3,208	3,346	1190	306,81	5,430	5,663	1610	438,69	7,764	8,098
360	70,73	1,252	1,306	780	184,19	3,260	3,400	1200	309,87	5,484	5,720	1620	441,90	7,821	8,157
370	73,14	1,295	1,350	790	187,11	3,312	3,454	1210	312,94	5,539	5,777	1630	445,13	7,878	8,217
380	75,57	1,338	1,395	800	190,03	3,363	3,508	1220	316,02	5,593	5,833	1640	448,35	7,935	8,276
390	78,02	1,381	1,440	810	192,96	3,415	3,562	1230	319,09	5,648	5,890	1650	451,58	7,992	8,336
400	80,47	1,424	1,485	820	195,89	3,467	3,616	1240	322,18	5,702	5,947	1660	454,81	8,050	8,395
410	82,94	1,468	1,531	830	198,82	3,519	3,670	1250	325,26	5,757	6,004	1670	458,05	8,107	8,455
420	85,42	1,512	1,577	840	201,76	3,571	3,724	1260	328,35	5,811	6,061	1680	461,28	8,164	8,515
430	87,91	1,556	1,623	850	204,70	3,623	3,779	1270	331,44	5,866	6,118	1690	464,53	8,222	8,575
440	90,42	1,600	1,669	860	207,64	3,675	3,833	1280	334,53	5,921	6,175	1700	467,77	8,279	8,635
450	92,94	1,645	1,716	870	210,59	3,727	3,887	1290	337,63	5,976	6,232	1710	471,02	8,337	8,695
460	95,47	1,690	1,762	880	213,54	3,779	3,942	1300	340,73	6,031	6,290	1720	474,28	8,394	8,755
470	98,02	1,735	1,809	890	216,50	3,832	3,996	1310	343,84	6,086	6,347	1730	477,53	8,452	8,815
480	100,57	1,780	1,857	900	219,45	3,884	4,051	1320	346,95	6,141	6,404	1740	480,79	8,510	8,875
490	103,15	1,826	1,904	910	222,42	3,937	4,106	1330	350,06	6,196	6,462	1750	484,06	8,567	8,935
500	105,73	1,871	1,952	920	225,38	3,989	4,160	1340	353,18	6,251	6,519	1760	487,33	8,625	8,996
510	108,33	1,917	2,000	930	228,35	4,042	4,215	1350	356,30	6,306	6,577	1770	490,60	8,683	9,056
520	110,93	1,963	2,048	940	231,32	4,094	4,270	1360	359,42	6,361	6,635	1780	493,87	8,741	9,116
530	113,56	2,010	2,096	950	234,30	4,147	4,325	1370	362,55	6,417	6,692	1790	497,15	8,799	9,177
540	116,19	2,056	2,145	960	237,28	4,200	4,380	1380	365,68	6,472	6,750	1800	500,43	8,857	9,238
550	118,84	2,103	2,194	970	240,26	4,252	4,435	1390	368,82	6,528	6,808	1810	503,72	8,915	9,298
560	121,50	2,150	2,243	980	243,25	4,305	4,490	1400	371,95	6,583	6,866	1820	507,01	8,974	9,359
570	124,17	2,198	2,292	990	246,24	4,358	4,545	1410	375,10	6,639	6,924	1830	510,30	9,032	9,420
580	126,86	2,245	2,342	1000	249,23	4,411	4,601	1420	378,24	6,695	6,982	1840	513,60	9,090	9,481
590	129,56	2,293	2,392	1010	252,23	4,464	4,656	1430	381,39	6,750	7,040	1850	516,90	9,149	9,541
600	132,27	2,341	2,442	1020	255,23	4,517	4,711	1440	384,54	6,806	7,098	1860	520,20	9,207	9,602
610	135,13	2,392	2,494	1030	258,24	4,571	4,767	1450	387,70	6,862	7,157	1870	523,51	9,266	9,663
620	137,98	2,442	2,547	1040	261,25	4,624	4,822	1460	390,86	6,918	7,215	1880	526,82	9,324	9,725
630	140,85	2,493	2,600	1050	264,26	4,677	4,878	1470	394,02	6,974	7,273	1890	530,13	9,383	9,786
640	143,71	2,544	2,653	1060	267,28	4,731	4,934	1480	397,19	7,030	7,332	1900	533,45	9,442	9,847
650	146,58	2,594	2,706	1070	270,29	4,784	4,989	1490	400,36	7,086	7,390	1910	536,77	9,500	9,908
660	149,45	2,645	2,759	1080	273,32	4,837	5,045	1500	403,53	7,142	7,449	1920	540,10	9,559	9,970
670	152,33	2,696	2,812	1090	276,34	4,891	5,101	1510	406,71	7,198	7,508	1930	543,43	9,618	10,031
680	155,20	2,747	2,865	1100	279,37	4,945	5,157	1520	409,89	7,255	7,566	1940	546,76	9,677	10,093
690	158,09	2,798	2,918	1110	282,41	4,998	5,213	1530	413,08	7,311	7,625	1950	550,10	9,736	10,154
700	160,97	2,849	2,971	1120	285,45	5,052	5,269	1540	416,27	7,368	7,684	1960	553,44	9,795	10,216

$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$
1970	556,78	9,854	10,278	2380	696,95	12,335	12,865	2790	843,18	14,923	15,564	3200	995,45	17,618	18,375
1980	560,13	9,914	10,339	2390	700,45	12,397	12,930	2800	846,82	14,988	15,631	3210	999,24	17,686	18,445
1990	563,48	9,973	10,401	2400	703,95	12,459	12,994	2810	850,46	15,052	15,699	3220	1003,0	17,753	18,515
2000	566,83	10,032	10,463	2410	707,45	12,521	13,059	2820	854,11	15,117	15,766	3230	1006,8	17,820	18,585
2010	570,19	10,092	10,525	2420	710,95	12,583	13,124	2830	857,77	15,182	15,834	3240	1010,6	17,887	18,655
2020	573,55	10,151	10,587	2430	714,46	12,645	13,188	2840	861,42	15,246	15,901	3250	1014,4	17,954	18,725
2030	576,91	10,211	10,649	2440	717,97	12,707	13,253	2850	865,08	15,311	15,969	3260	1018,2	18,022	18,796
2040	580,28	10,270	10,711	2450	721,49	12,770	13,318	2860	868,75	15,376	16,036	3270	1022,1	18,089	18,866
2050	583,65	10,330	10,774	2460	725,01	12,832	13,383	2870	872,41	15,441	16,104	3280	1025,9	18,157	18,937
2060	587,03	10,390	10,836	2470	728,53	12,894	13,448	2880	876,08	15,506	16,172	3290	1029,7	18,224	19,007
2070	590,41	10,450	10,898	2480	732,06	12,957	13,513	2890	879,76	15,571	16,240	3300	1033,5	18,292	19,078
2080	593,79	10,510	10,961	2490	735,59	13,019	13,578	2900	883,44	15,636	16,307	3310	1037,3	18,360	19,148
2090	597,18	10,569	11,023	2500	739,12	13,082	13,644	2910	887,12	15,701	16,375	3320	1041,2	18,428	19,219
2100	600,57	10,629	11,086	2510	742,66	13,144	13,709	2920	890,80	15,766	16,443	3330	1045,0	18,495	19,290
2110	603,96	10,690	11,149	2520	746,20	13,207	13,774	2930	894,49	15,832	16,511	3340	1048,8	18,563	19,360
2120	607,36	10,750	11,211	2530	749,75	13,270	13,840	2940	898,18	15,897	16,580	3350	1052,7	18,631	19,431
2130	610,76	10,810	11,274	2540	753,30	13,333	13,905	2950	901,88	15,962	16,648	3360	1056,5	18,699	19,502
2140	614,17	10,870	11,337	2550	756,85	13,395	13,971	2960	905,58	16,028	16,716	3370	1060,4	18,767	19,573
2150	617,57	10,930	11,400	2560	760,40	13,458	14,036	2970	909,28	16,093	16,785	3380	1064,2	18,836	19,644
2160	620,99	10,991	11,463	2570	763,96	13,521	14,102	2980	912,99	16,159	16,853	3390	1068,1	18,904	19,716
2170	624,40	11,051	11,526	2580	767,53	13,584	14,168	2990	916,70	16,225	16,921	3400	1071,9	18,972	19,787
2180	627,82	11,112	11,589	2590	771,09	13,648	14,234	3000	920,41	16,290	16,990	3410	1075,8	19,040	19,858
2190	631,24	11,172	11,652	2600	774,66	13,711	14,300	3010	924,13	16,356	17,059	3420	1079,7	19,109	19,929
2200	634,67	11,233	11,715	2610	778,24	13,774	14,366	3020	927,85	16,422	17,127	3430	1083,5	19,177	20,001
2210	638,10	11,294	11,779	2620	781,81	13,837	14,432	3030	931,58	16,488	17,196	3440	1087,4	19,246	20,072
2220	641,53	11,354	11,842	2630	785,39	13,901	14,498	3040	935,31	16,554	17,265	3450	1091,3	19,314	20,144
2230	644,97	11,415	11,906	2640	788,98	13,964	14,564	3050	939,04	16,620	17,334	3460	1095,2	19,383	20,215
2240	648,41	11,476	11,969	2650	792,57	14,028	14,630	3060	942,77	16,686	17,403	3470	1099,0	19,452	20,287
2250	651,85	11,537	12,033	2660	796,16	14,091	14,696	3070	946,51	16,752	17,472	3480	1102,9	19,521	20,359
2260	655,30	11,598	12,096	2670	799,75	14,155	14,763	3080	950,26	16,819	17,541	3490	1106,8	19,589	20,431
2270	658,75	11,659	12,160	2680	803,35	14,219	14,829	3090	954,00	16,885	17,610	3500	1110,7	19,658	20,503
2280	662,21	11,720	12,224	2690	806,95	14,282	14,896	3100	957,75	16,951	17,679	3510	1114,6	19,727	20,574
2290	665,66	11,782	12,288	2700	810,56	14,346	14,962	3110	961,51	17,018	17,748	3520	1118,5	19,796	20,646
2300	669,13	11,843	12,351	2710	814,17	14,410	15,029	3120	965,26	17,084	17,818	3530	1122,4	19,865	20,719
2310	672,59	11,904	12,415	2720	817,78	14,474	15,096	3130	969,02	17,151	17,887	3540	1126,3	19,935	20,791
2320	676,06	11,966	12,479	2730	821,40	14,538	15,162	3140	972,79	17,217	17,957	3550	1130,2	20,004	20,863
2330	679,53	12,027	12,544	2740	825,02	14,602	15,229	3150	976,56	17,284	18,026	3560	1134,1	20,073	20,935
2340	683,01	12,089	12,608	2750	828,64	14,666	15,296	3160	980,33	17,351	18,096	3570	1138,1	20,143	21,008
2350	686,49	12,150	12,672	2760	832,27	14,730	15,363	3170	984,10	17,418	18,166	3580	1142,0	20,212	21,080
2360	689,97	12,212	12,736	2770	835,90	14,795	15,430	3180	987,88	17,485	18,235	3590	1145,9	20,281	21,152
2370	693,46	12,274	12,801	2780	839,54	14,859	15,497	3190	991,66	17,551	18,305	3600	1149,8	20,351	21,225

Stefan-Boltzmann Lamp 1008523

Instruction manual

02/24 NF/ALF/UD



1. Safety instructions

The Stefan-Boltzmann lamp conforms to the safety stipulations for electrical measuring, control and laboratory instruments as specified in DIN EN 61010 part 1. It is intended for use in dry rooms suitable for the operation of electrical equipment.

Safe operation of the equipment can be assured as long as it is used as stipulated. However, safety cannot be guaranteed if the equipment is used incorrectly or handled without due care and attention.

Caution: When in operation, the lamp can become very hot. There is then a risk of burns if it is touched. This can also result in greasy residues being burned onto the lamp.

- Do not touch the lamp with your fingers.
- Allow the lamp to cool after the experiment has been completed.

Note:

Applying a voltage of more than 13 V to the terminals is likely to destroy the filament.

- Never apply a voltage higher than 13 V across the two 4-mm sockets.

2. Description

The Stefan-Boltzmann lamp is a high temperature source with a tungsten filament. It is designed to produce thermal radiation and for investigating how such radiation depends on the temperature. It can be used to confirm the Stefan-Boltzmann law, as stated in the following equation:

$$P = \varepsilon \cdot \sigma \cdot A \cdot T^4 .$$

P in this equation is the power radiated, T is the absolute temperature of the filament, A is the area of the filament's surface, σ is the Stefan-Boltzmann constant and ε is a dimensionless constant of a value between 0 and 1. The temperature of the lamp can be determined from the resistance of the filament.

The filament represents a good approximation of a point source of heat radiation and is thus highly suitable for investigating the inverse square law for heat radiation.

3. Equipment

1 Stefan Boltzmann Lamp
1 Stand Rod, 130 mm long

4. Technical data

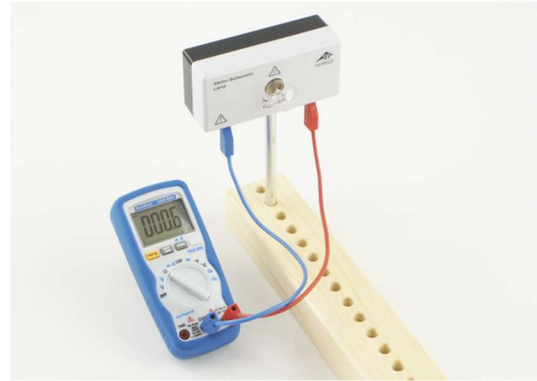
Nominal voltage:	12 V DC
Nominal current:	1.75 A
Nominal power:	21 W
Max. operating parameters:	13 V DC/2 A
Maximum temperature of filament:	3600 K
Distance of filament from rod:	25 mm

5. Sample measurements

Additionally required:

1 Thermopile	1000824
1 DC Power Supply, 20 V, 5 A (@230V)	1003312
or	
1 DC Power Supply, 20 V, 5 A (@115V)	1003311
1 Digital Multimeter P3340	1002785
2 Digital Multimeters P1035	1002781
2 Barrel Feet, 1 kg	1002834
1 Set of 15 Safety Experiment Leads, 75 cm	1002843

5.1 Measurement of filament resistance at room temperature



- Insert one of the measuring leads into the COM socket of the digital multimeter P3340 (1002785) and one into its V Ω mA socket, then short the leads together.
- Select the Ω measuring range, wait for zero to be displayed and then briefly press the REL button.
- Break the contact between the leads and insert them into the sockets of the Stefan-Boltzmann lamp.
- Read off the resistance value R_{ref} and make a note of it (Tab. 1).
- Remove the measuring leads.
- Use the multimeter's temperature sensor to measure the ambient temperature T_{ref} in the vicinity of the lamp in Kelvin and make a note of it (Tab. 1).

Tab. 1: Value of filament resistance measured at room temperature

R_{ref}	0.541 Ω
T_{ref}	297 K

5.2 Measurement of radiant intensity as a function of the temperature of the filament



- Connect the thermopile to the P3340 digital multimeter (1002785).
- Set up the Stefan-Boltzmann lamp in front of the thermopile and connect up the DC power supply and the two P1035 digital multimeters (1002781).
- Apply a voltage in steps of 1 V up to a maximum of 12 V, measure the lamp voltage U , the lamp current I , and use the thermopile to measure the radiant intensity Φ (5.3, Tab. 2).

5.3 Evaluation

- Calculate $R = U/I$ (Tab. 2).
- Now the values determined, T_{ref} , R_{ref} , R , can be used along with the temperature coefficient of resistance for tungsten $\alpha = 4.4 \cdot 10^{-3} \text{ K}^{-1}$ to calculate the temperature of the filament by means of the following formula (Tab. 2):

$$T = \left(\frac{R - R_{\text{ref}}}{\alpha \cdot R_{\text{ref}}} \right) + T_{\text{ref}}$$

One possible alternative method for determining the temperature T of the filament is to calculate the quotients R/R_{ref} and then use Fig. 2 or Tab. 3 to find the temperature.

Note: In Table 3 the quotient R/R_{ref} is specified for $T_{\text{ref}} = 300 \text{ K}$ and for $T_{\text{ref}} = 290 \text{ K}$. It is possible to determine the temperature more precisely by interpolating between these two reference values to take account of the actual room temperature.

- Plot Φ as a function of T^4 (Fig. 3).

Tab. 2: Values for the resistance R and the temperature T of the filament calculated from the measured values for the lamp voltage U and the lamp current I , as well as the radiated intensity Φ measured with the thermopile

U / V	I / A	R / Ω	T / K	Φ / V
0.00369	0.006	0.615	328	0
1.0502	0.554	1.896	854	0.0001
2.033	0.706	2.879	1259	0.0004
3.012	0.837	3.599	1554	0.0011
4.003	0.958	4.178	1792	0.0019
5.012	1.071	4.679	1998	0.0029
6.017	1.174	5.125	2181	0.0042
7.074	1.276	5.5434	2353	0.0058
8.028	1.362	5.894	2497	0.0072
9.011	1.446	6.232	2636	0.0088
10.088	1.534	6.576	2777	0.0106
11.02	1.607	6.8575	2893	0.0125
11.685	1.68	6.955	2933	0.0145

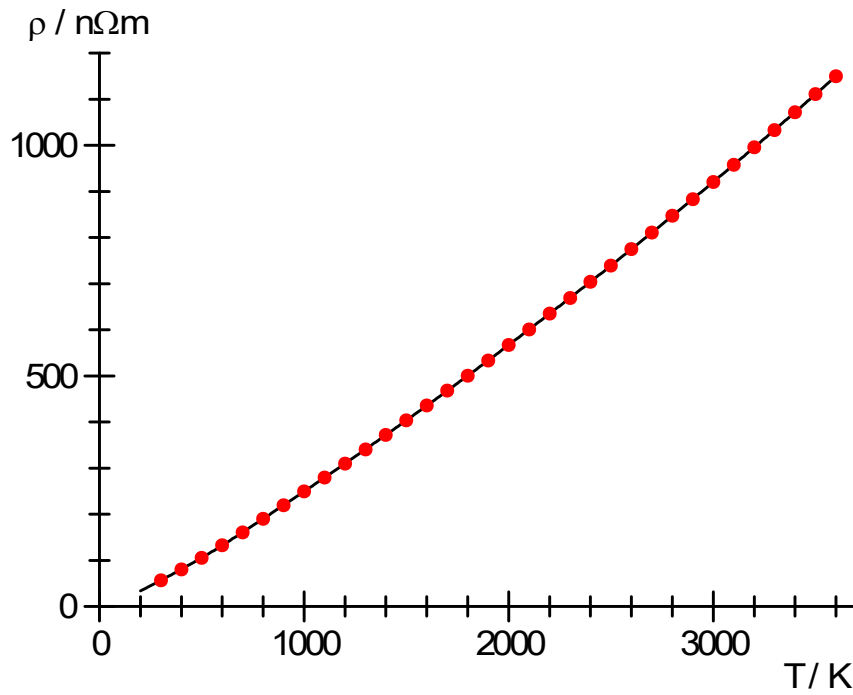


Fig. 1: Electrical resistivity ρ of tungsten as a function of absolute temperature T (see Tab. 3). Curve based on measurements made by Zerda, T.W., Texas Christian University, 2001

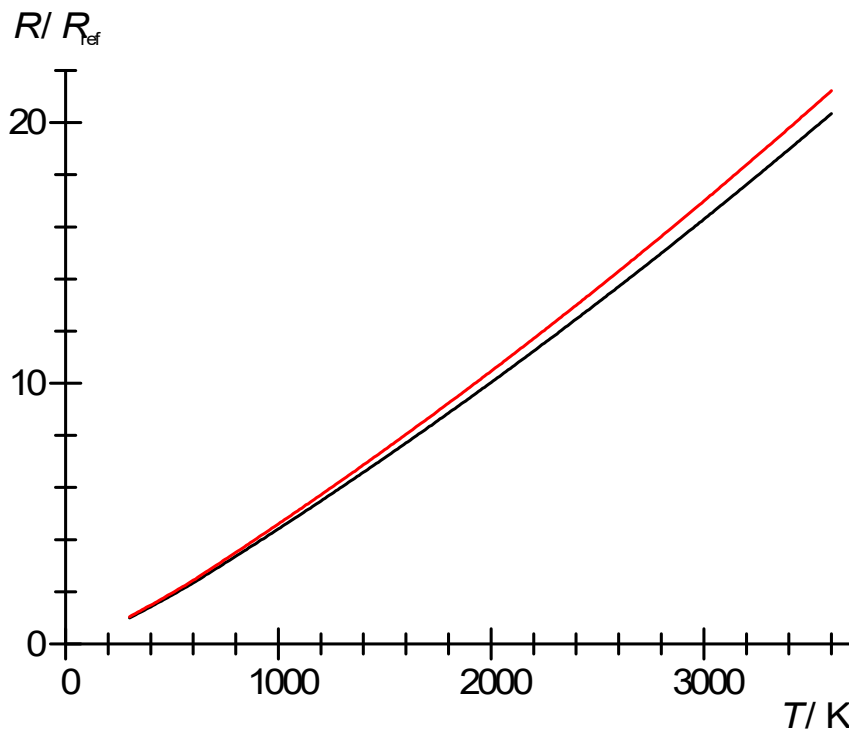


Fig. 2: Resistances ratios $R(T)/R_{300K}$ (black) and $R(T)/R_{290}$ (red) calculated from the values shown in Fig. 1 (see Tab. 3)

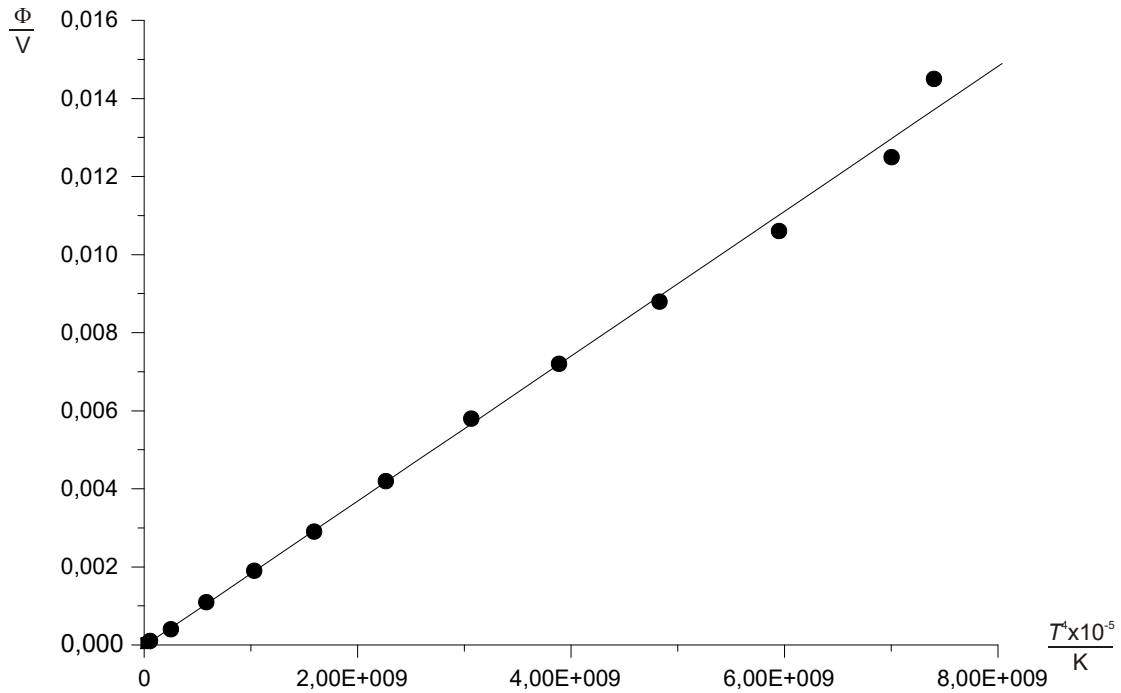


Fig. 3: Radiant intensity Φ as a function of temperature T

6. Changing bulbs

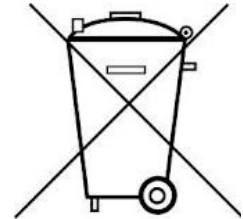
In order to change the bulb, the following equipment is also required:

- 1 Bulb, 12 V/21 W, socket BA15S
- 1 Screwdriver
- 1 Piece of sandpaper
- 1 Soldering iron
- Solder

- Unscrew the back of the housing.
- Unsolder the bulb.
- Sand down the contact surfaces where the wires are to be soldered to the new bulb and tin them with solder.
- Set the bulb in position and solder it in place.
- Test the lamp by applying a voltage of 12 V.
- Screw the housing back together.

7. Disposal

- Packaging should be disposed of at local recycling centres.
- Should the equipment need to be scrapped, it must not be disposed of in normal household waste. Local regulations for the disposal of electrical equipment should be observed.



8. Appendix

Tab. 3: Specific resistance ρ of tungsten as a function of the absolute temperature T and calculated resistance ratios $R(T)/R_{300K}$ or $R(T)/R_{290K}$ (see Fig. 1 and Fig. 2)

$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$
290	54.17	1.000		710	163.86	2.900	3.025	1130	288.49	5.106	5.325	1550	419.46	7.424	7.743
300	56.50	1.000	1.043	720	166.76	2.951	3.078	1140	291.53	5.160	5.381	1560	422.65	7.481	7.802
310	58.84	1.041	1.086	730	169.65	3.003	3.132	1150	294.58	5.214	5.438	1570	425.85	7.537	7.861
320	61.19	1.083	1.130	740	172.55	3.054	3.185	1160	297.63	5.268	5.494	1580	429.06	7.594	7.920

330	63.56	1.125	1.173	750	175.46	3.105	3.239	1170	300.69	5.322	5.550	1590	432.26	7.651	7.979
340	65.93	1.167	1.217	760	178.37	3.157	3.292	1180	303.75	5.376	5.607	1600	435.47	7.707	8.038
350	68.33	1.209	1.261	770	181.28	3.208	3.346	1190	306.81	5.430	5.663	1610	438.69	7.764	8.098
360	70.73	1.252	1.306	780	184.19	3.260	3.400	1200	309.87	5.484	5.720	1620	441.90	7.821	8.157
370	73.14	1.295	1.350	790	187.11	3.312	3.454	1210	312.94	5.539	5.777	1630	445.13	7.878	8.217
380	75.57	1.338	1.395	800	190.03	3.363	3.508	1220	316.02	5.593	5.833	1640	448.35	7.935	8.276
390	78.02	1.381	1.440	810	192.96	3.415	3.562	1230	319.09	5.648	5.890	1650	451.58	7.992	8.336
400	80.47	1.424	1.485	820	195.89	3.467	3.616	1240	322.18	5.702	5.947	1660	454.81	8.050	8.395
410	82.94	1.468	1.531	830	198.82	3.519	3.670	1250	325.26	5.757	6.004	1670	458.05	8.107	8.455
420	85.42	1.512	1.577	840	201.76	3.571	3.724	1260	328.35	5.811	6.061	1680	461.28	8.164	8.515
430	87.91	1.556	1.623	850	204.70	3.623	3.779	1270	331.44	5.866	6.118	1690	464.53	8.222	8.575
440	90.42	1.600	1.669	860	207.64	3.675	3.833	1280	334.53	5.921	6.175	1700	467.77	8.279	8.635
450	92.94	1.645	1.716	870	210.59	3.727	3.887	1290	337.63	5.976	6.232	1710	471.02	8.337	8.695
460	95.47	1.690	1.762	880	213.54	3.779	3.942	1300	340.73	6.031	6.290	1720	474.28	8.394	8.755
470	98.02	1.735	1.809	890	216.50	3.832	3.996	1310	343.84	6.086	6.347	1730	477.53	8.452	8.815
480	100.57	1.780	1.857	900	219.45	3.884	4.051	1320	346.95	6.141	6.404	1740	480.79	8.510	8.875
490	103.15	1.826	1.904	910	222.42	3.937	4.106	1330	350.06	6.196	6.462	1750	484.06	8.567	8.935
500	105.73	1.871	1.952	920	225.38	3.989	4.160	1340	353.18	6.251	6.519	1760	487.33	8.625	8.996
510	108.33	1.917	2.000	930	228.35	4.042	4.215	1350	356.30	6.306	6.577	1770	490.60	8.683	9.056
520	110.93	1.963	2.048	940	231.32	4.094	4.270	1360	359.42	6.361	6.635	1780	493.87	8.741	9.116
530	113.56	2.010	2.096	950	234.30	4.147	4.325	1370	362.55	6.417	6.692	1790	497.15	8.799	9.177
540	116.19	2.056	2.145	960	237.28	4.200	4.380	1380	365.68	6.472	6.750	1800	500.43	8.857	9.238
550	118.84	2.103	2.194	970	240.26	4.252	4.435	1390	368.82	6.528	6.808	1810	503.72	8.915	9.298
560	121.50	2.150	2.243	980	243.25	4.305	4.490	1400	371.95	6.583	6.866	1820	507.01	8.974	9.359
570	124.17	2.198	2.292	990	246.24	4.358	4.545	1410	375.10	6.639	6.924	1830	510.30	9.032	9.420
580	126.86	2.245	2.342	1000	249.23	4.411	4.601	1420	378.24	6.695	6.982	1840	513.60	9.090	9.481
590	129.56	2.293	2.392	1010	252.23	4.464	4.656	1430	381.39	6.750	7.040	1850	516.90	9.149	9.541
600	132.27	2.341	2.442	1020	255.23	4.517	4.711	1440	384.54	6.806	7.098	1860	520.20	9.207	9.602
610	135.13	2.392	2.494	1030	258.24	4.571	4.767	1450	387.70	6.862	7.157	1870	523.51	9.266	9.663
620	137.98	2.442	2.547	1040	261.25	4.624	4.822	1460	390.86	6.918	7.215	1880	526.82	9.324	9.725
630	140.85	2.493	2.600	1050	264.26	4.677	4.878	1470	394.02	6.974	7.273	1890	530.13	9.383	9.786
640	143.71	2.544	2.653	1060	267.28	4.731	4.934	1480	397.19	7.030	7.332	1900	533.45	9.442	9.847
650	146.58	2.594	2.706	1070	270.29	4.784	4.989	1490	400.36	7.086	7.390	1910	536.77	9.500	9.908
660	149.45	2.645	2.759	1080	273.32	4.837	5.045	1500	403.53	7.142	7.449	1920	540.10	9.559	9.970
670	152.33	2.696	2.812	1090	276.34	4.891	5.101	1510	406.71	7.198	7.508	1930	543.43	9.618	10.031
680	155.20	2.747	2.865	1100	279.37	4.945	5.157	1520	409.89	7.255	7.566	1940	546.76	9.677	10.093
690	158.09	2.798	2.918	1110	282.41	4.998	5.213	1530	413.08	7.311	7.625	1950	550.10	9.736	10.154
700	160.97	2.849	2.971	1120	285.45	5.052	5.269	1540	416.27	7.368	7.684	1960	553.44	9.795	10.216

$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$
1970	556.78	9.854	10.278	2380	696.95	12.335	12.865	2790	843.18	14.923	15.564	3200	995.45	17.618	18.375
1980	560.13	9.914	10.339	2390	700.45	12.397	12.930	2800	846.82	14.988	15.631	3210	999.24	17.686	18.445
1990	563.48	9.973	10.401	2400	703.95	12.459	12.994	2810	850.46	15.052	15.699	3220	1003.0	17.753	18.515
2000	566.83	10.032	10.463	2410	707.45	12.521	13.059	2820	854.11	15.117	15.766	3230	1006.8	17.820	18.585
2010	570.19	10.092	10.525	2420	710.95	12.583	13.124	2830	857.77	15.182	15.834	3240	1010.6	17.887	18.655
2020	573.55	10.151	10.587	2430	714.46	12.645	13.188	2840	861.42	15.246	15.901	3250	1014.4	17.954	18.725
2030	576.91	10.211	10.649	2440	717.97	12.707	13.253	2850	865.08	15.311	15.969	3260	1018.2	18.022	18.796
2040	580.28	10.270	10.711	2450	721.49	12.770	13.318	2860	868.75	15.376	16.036	3270	1022.1	18.089	18.866
2050	583.65	10.330	10.774	2460	725.01	12.832	13.383	2870	872.41	15.441	16.104	3280	1025.9	18.157	18.937
2060	587.03	10.390	10.836	2470	728.53	12.894	13.448	2880	876.08	15.506	16.172	3290	1029.7	18.224	19.007
2070	590.41	10.450	10.898	2480	732.06	12.957	13.513	2890	879.76	15.571	16.240	3300	1033.5	18.292	19.078
2080	593.79	10.510	10.961	2490	735.59	13.019	13.578	2900	883.44	15.636	16.307	3310	1037.3	18.360	19.148
2090	597.18	10.569	11.023	2500	739.12	13.082	13.644	2910	887.12	15.701	16.375	3320	1041.2	18.428	19.219
2100	600.57	10.629	11.086	2510	742.66	13.144	13.709	2920	890.80	15.766	16.443	3330	1045.0	18.495	19.290
2110	603.96	10.690	11.149	2520	746.20	13.207	13.774	2930	894.49	15.832	16.511	3340	1048.8	18.563	19.360
2120	607.36	10.750	11.211	2530	749.75	13.270	13.840	2940	898.18	15.897	16.580	3350	1052.7	18.631	19.431
2130	610.76	10.810	11.274	2540	753.30	13.333	13.905	2950	901.88	15.962	16.648	3360	1056.5	18.699	19.502
2140	614.17	10.870	11.337	2550	756.85	13.395	13.971	2960	905.58	16.028	16.716	3370	1060.4	18.767	19.573
2150	617.57	10.930	11.400	2560	760.40	13.458	14.036	2970	909.28	16.093	16.785	3380	1064.2	18.836	19.644
2160	620.99	10.991	11.463	2570	763.96	13.521	14.102	2980	912.99	16.159	16.853	3390	1068.1	18.904	19.716
2170	624.40	11.051	11.526	2580	767.53	13.584	14.168	2990	916.70	16.225	16.921	3400	1071.9	18.972	19.787
2180	627.82	11.112	11.589	2590	771.09	13.648	14.234	3000	920.41	16.290	16.990	3410	1075.8	19.040	19.858
2190	631.24	11.172	11.652	2600	774.66	13.711	14.300	3010	924.13	16.356	17.059	3420	1079.7	19.109	19.929
2200	634.67	11.233	11.715	2610	778.24	13.774	14.366	3020	927.85	16.422	17.127	3430	1083.5	19.177	20.001
2210	638.10	11.294	11.779	2620	781.81	13.837	14.432	3030	931.58	16.488	17.196	3440	1087.4	19.246	20.072
2220	641.53	11.354	11.842	2630	785.39	13.901	14.498	3040	935.31	16.554	17.265	3450	1091.3	19.314	20.144
2230	644.97	11.415	11.906	2640	788.98	13.964	14.564	3050	939.04	16.620	17.334	3460	1095.2	19.383	20.215
2240	648.41	11.476	11.969	2650	792.57	14.028	14.630	3060	942.77	16.686	17.403	3470	1099.0	19.452	20.287
2250	651.85	11.537	12.033	2660	796.16	14.091	14.696	3070	946.51	16.752	17.472	3480	1102.9	19.521	20.359
2260	655.30	11.598	12.096	2670	799.75	14.155	14.763	3080	950.26	16.819	17.541	3490	1106.8	19.589	20.431
2270	658.75	11.659	12.160	2680	803.35	14.219	14.829	3090	954.00	16.885	17.610	3500	1110.7	19.658	20.503
2280	662.21	11.720	12.224	2690	806.95	14.282	14.896	3100	957.75	16.951	17.679	3510	1114.6	19.727	20.574
2290	665.66	11.782	12.288	2700	810.56	14.346	14.962	3110	961.51	17.018	17.748	3520	1118.5	19.796	20.646
2300	669.13	11.843	12.351	2710	814.17	14.410	15.029	3120	965.26	17.084	17.818	3530	1122.4	19.865	20.719
2310	672.59	11.904	12.415	2720	817.78	14.474	15.096	3130	969.02	17.151	17.887	3540	1126.3	19.935	20.791
2320	676.06	11.966	12.479	2730	821.40	14.538	15.162	3140	972.79	17.217	17.957	3550	1130.2	20.004	20.863
2330	679.53	12.027	12.544	2740	825.02	14.602	15.229	3150	976.56	17.284	18.026	3560	1134.1	20.073	20.935
2340	683.01	12.089	12.608	2750	828.64	14.666	15.296	3160	980.33	17.351	18.096	3570	1138.1	20.143	21.008
2350	686.49	12.150	12.672	2760	832.27	14.730	15.363	3170	984.10	17.418	18.166	3580	1142.0	20.212	21.080
2360	689.97	12.212	12.736	2770	835.90	14.795	15.430	3180	987.88	17.485	18.235	3590	1145.9	20.281	21.152
2370	693.46	12.274	12.801	2780	839.54	14.859	15.497	3190	991.66	17.551	18.305	3600	1149.8	20.351	21.225

Lámpara de Stefan-Boltzmann 1008523

Instrucciones de uso

02/24 NF/ALF/UD



1. Advertencias de seguridad

La lámpara de Stefan-Boltzmann corresponde a las determinaciones de seguridad para, aparatos eléctricos, de medida, de control y regulación y aparatos de laboratorio según DIN EN 61010 Parte 1. Ella está prevista para su funcionamiento en recintos secos, que sean apropiados para instalaciones eléctricas.

Con su uso adecuado de acuerdo a su finalidad se garantiza el funcionamiento seguro de la instalación. Sin embargo, la seguridad no se garantiza cuando los aparatos no se manejan en forma apropiada y sin el cuidado correspondiente.

¡Atención! Durante el funcionamiento la lámpara se calienta fuertemente. En caso de contacto se corre peligro de fuertes quemaduras! Además, trazas de de grasa se impregnan en la superficie de la lámpara.

- La lámpara no se debe tocar con los dedos.
- Después de finalizar el experimento se debe dejar enfriar la lámpara.

Observación: Con tensiones de conexión por encima de 13 V se destroza el filamento incandescente.

- ¡Nunca se debe conectar una tensión mayor de 13 V en los dos casquillos de 4 mm!

2. Descripción

La lámpara de Stefan-Boltzmann es una fuente de alta temperatura con un filamento incandescente de tungsteno. Ella sirve para producir una fuerte radiación de calor y para el estudio de su dependencia con la temperatura resp. para la comprobación de la ley de Stefan-Boltzmann en la forma:

$$P = \varepsilon \cdot \sigma \cdot A \cdot T^4 .$$

En este caso P es la potencia de radiación emitida, T la temperatura absoluta del filamento incandescente, A su superficie, σ la constante de Stefan-Boltzmann y ε una constante sin dimensión entre 0 y 1. La temperatura de la lámpara se calcula indirectamente a partir de la resistencia del filamento incandescente.

El filamento incandescente representa en buena aproximación una fuente de radiación térmica puntual y por lo tanto es apropiado para el estudio de la ley del inverso del cuadrado de la distancia.

3. Volumen de suministro

1 Lámpara de Stefan-Boltzmann
1 Varilla soporte de 130 mm de largo

4. Datos técnicos

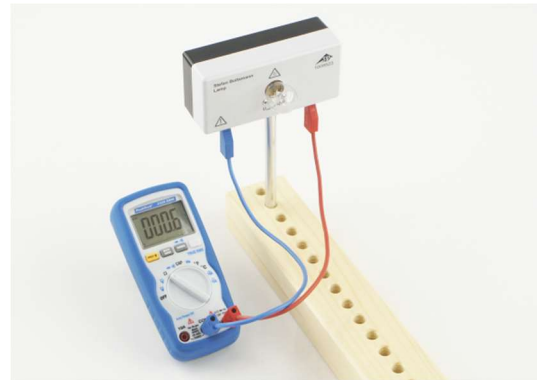
Tensión nominal:	12 V CC
Corriente nominal:	1,75 A
Potencia nominal:	21 W
Valores de trabajo máx.:	13 V CC / 2 A
Temperatura max. del filamento incandescente:	3600 K
Distancia del filamento Incandescente hasta la varilla soporte:	25 mm

5. Ejemplo de medida

Se requiere adicionalmente:

1 Termopila de Moll	1000824
1 Fuente de alimentación CC, 20 V, 5 A (@230V)	1003312
resp.	
1 Fuente de alimentación CC, 20 V, 5 A (@115V)	1003311
1 Multímetro digital P3340	1002785
2 Multímetros digitales P1035	1002781
2 Bases con orificio central 1000 g	1003034
1 Juego de 15 cables de experimentación de seguridad, 75 cm	1002843

5.1 Medición de la resistencia del filamento incandescente a temperatura ambiente



- Se inserta un cable de medida en el casquillo COM y uno en el casquillo V Ω mA-del multímetro digital P3340 (1002785) y luego se puentean los dos cables entre sí.
- Se selecciona el alcance de Ω y se espera hasta que la indicación llegue a "0" y a continuación se pulsa la tecla REL.
- Se abre el puente de cortocircuito de los dos cables de medida se insertan en los dos casquillos de la lámpara de Stefan-Boltzmann.
- Se lee y se anota el valor de la resistencia R_{ref} (Tab. 1).
- Se retiran los cables de medida.
- Con el sensor de temperatura del multímetro en la cercanía de la lámpara se mide y se anota la temperatura del medio T_{ref} en Kelvin (Tab. 1).

Tab. 1: Valor de la resistencia del filamento medido a temperatura ambiente

R_{ref}	0,541 Ω
T_{ref}	297 K

5.2 Medición de la intensidad de la radiación en dependencia con la temperatura del filamento incandescente determinada



- Se conecta la termopila con el multímetro digital P3340 (1002785).
- Se monta la lámpara de Stefan-Boltzmann enfrente de la termopila y se conecta con la fuente de alimentación de CC y con los dos multímetros digitales P1035 (1002781).
- Se aumenta la tensión U cada vez en 1 V hasta llegar a 12 V max. Se miden cada vez la tensión U y la corriente I de la lámpara y, con la termopila, la intensidad térmica irradiada Φ (5.3, Tab. 2).

5.3 Evaluación

- Se calcula $R = U/I$ (Tab. 2).
- Con los valores determinados para T_{ref} , R_{ref} , R y el coeficiente resistencia-temperatura para el tungsteno $\alpha = 4,4 \cdot 10^{-3} \text{ K}^{-1}$ se puede calcular la temperatura del filamento incandescente (Tab. 2) según la fórmula

$$T = \left(\frac{R - R_{\text{ref}}}{\alpha \cdot R_{\text{ref}}} \right) + T_{\text{ref}}$$

Una posibilidad alternativa para determinación de la temperatura T del filamento incandescente es, calcular el cociente R / R_{ref} y con la ayuda de Fig. 2 respectivamente con Tab. 3 en el apéndice determinar la temperatura del filamento.

Observación: En Tab. 3 se indica el cociente R / R_{ref} tanto para $T_{\text{ref}} = 300 \text{ K}$ como para $T_{\text{ref}} = 290 \text{ K}$. Para una evaluación más exacta se puede interpolar entre estos valores, para tener en cuenta la verdadera temperatura del medio ambiente.

- Se representa Φ en dependencia con T^4 (Fig. 3)

Tab. 2: Valores de la resistencia R y la temperatura T del filamento calculado con los valores medidos de la tensión U y la corriente I de la lámpara y valores de la intensidad radiada Φ medida con la termopila.

U / V	I / A	R / Ω	T / K	Φ / V
0,00369	0,006	0,615	328	0
1,0502	0,554	1,896	854	0,0001
2,033	0,706	2,879	1259	0,0004
3,012	0,837	3,599	1554	0,0011
4,003	0,958	4,178	1792	0,0019
5,012	1,071	4,679	1998	0,0029
6,017	1,174	5,125	2181	0,0042
7,074	1,276	5,5434	2353	0,0058
8,028	1,362	5,894	2497	0,0072
9,011	1,446	6,232	2636	0,0088
10,088	1,534	6,576	2777	0,0106
11,02	1,607	6,8575	2893	0,0125
11,685	1,68	6,955	2933	0,0145

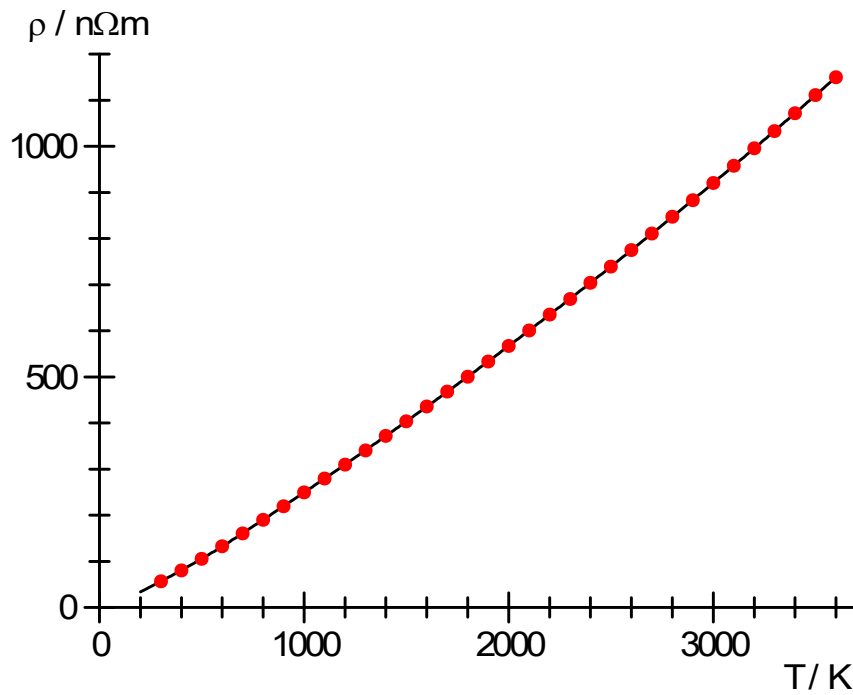


Fig. 1: Resistencia específica ρ del tungsteno en dependencia con la temperatura T (ver Tab 3). Curva adaptada a los valores de medida de Zerda, T.W., Texas Christian University. 2001

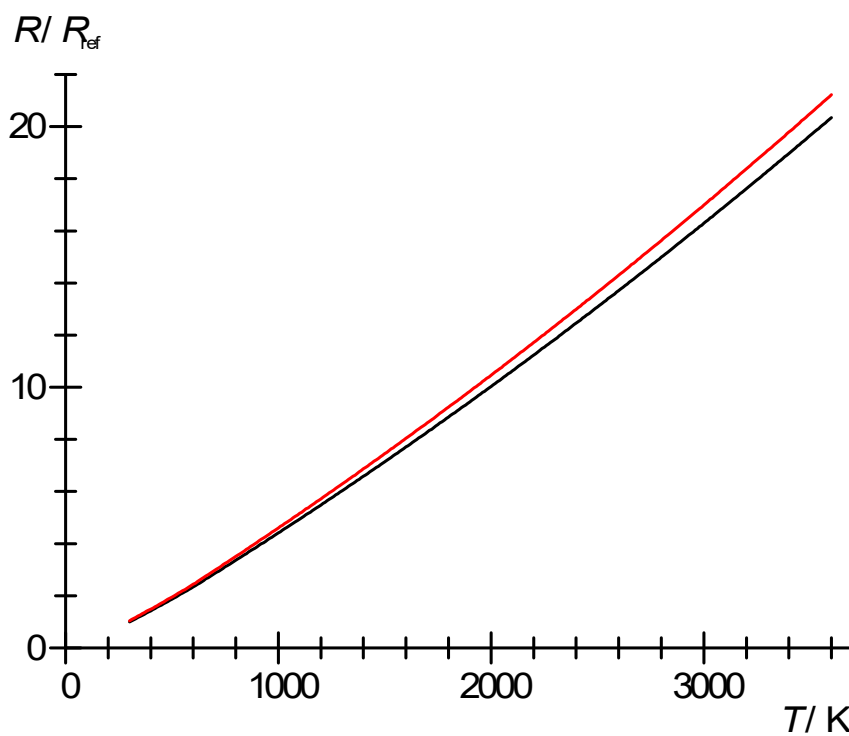


Fig. 2: Relaciones de resistencia $R(T) / R_{300\text{K}}$ (negro) resp. $R(T) / R_{290\text{K}}$ (rojo) calculados a partir de los valores de la Fig. 1 (ver Tab 3)

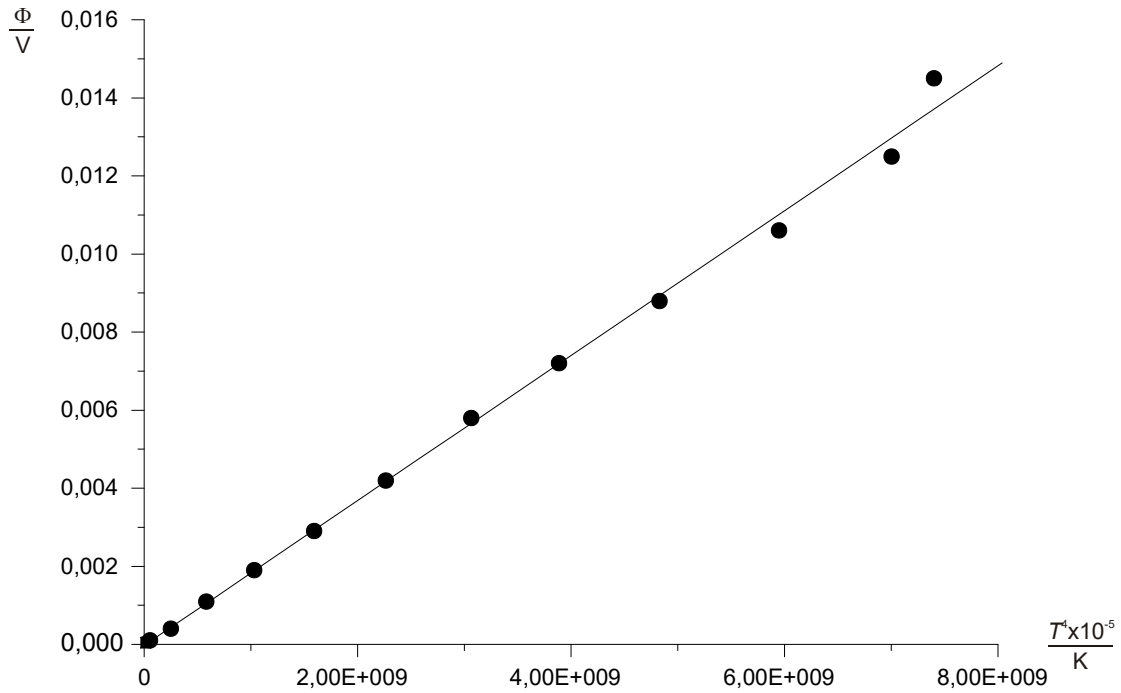


Fig. 3: Intensidad de la radiación Φ en dependencia con la temperatura T

6. Cambio de la lámpara

Para el cambio de la lámpara se requieren adicionalmente las siguientes elementos y herramientas:

1 Lámpara de 12 V / 21 W, Zócalo BA15S

1 Destornillador

1 Papel esmeril

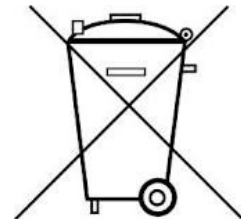
1 Soldador

Soldadura de estaño

- Se desatornilla la tapa posterior de la carcasa.
- Se desuelda la lámpara.
- Se suelda la nueva lámpara en los lugares en los cuales se suelda el alambre. Se lija con el papel de esmeril y se estaña.
- Se coloca la lámpara y se suelda.
- Se prueba la lámpara con 12 V.
- Se atornilla nuevamente la carcasa.

7. Desecho

- El embalaje y las componentes se desechan en los sitios de reciclaje locales.
- ¡En el caso eventual de una chatarrización, el aparato no debe formar parte de la basura doméstica normal! Se deben cumplir las prescripciones locales para el desecho de chatarra eléctrica.



8. Apéndice

Tab. 3 Resistencia específica ρ del tungsteno en dependencia con la temperatura absoluta T y las relaciones de resistencia $R(T) / R_{300K}$ resp. $R(T) / R_{290K}$ calculadas a partir de ellas (ver Fig. 1 y Fig. 2)

T K	ρ n Ω m	$R(T)$ R_{300K}	$R(T)$ R_{290K}	T K	ρ n Ω m	$R(T)$ R_{300K}	$R(T)$ R_{290K}	T K	ρ n Ω m	$R(T)$ R_{300K}	$R(T)$ R_{290K}	T K	ρ n Ω m	$R(T)$ R_{300K}	$R(T)$ R_{290K}
290	54,17	1,000		710	163,86	2,900	3,025	1130	288,49	5,106	5,325	1550	419,46	7,424	7,743
300	56,50	1,000	1,043	720	166,76	2,951	3,078	1140	291,53	5,160	5,381	1560	422,65	7,481	7,802

310	58,84	1,041	1,086	730	169,65	3,003	3,132	1150	294,58	5,214	5,438	1570	425,85	7,537	7,861
320	61,19	1,083	1,130	740	172,55	3,054	3,185	1160	297,63	5,268	5,494	1580	429,06	7,594	7,920
330	63,56	1,125	1,173	750	175,46	3,105	3,239	1170	300,69	5,322	5,550	1590	432,26	7,651	7,979
340	65,93	1,167	1,217	760	178,37	3,157	3,292	1180	303,75	5,376	5,607	1600	435,47	7,707	8,038
350	68,33	1,209	1,261	770	181,28	3,208	3,346	1190	306,81	5,430	5,663	1610	438,69	7,764	8,098
360	70,73	1,252	1,306	780	184,19	3,260	3,400	1200	309,87	5,484	5,720	1620	441,90	7,821	8,157
370	73,14	1,295	1,350	790	187,11	3,312	3,454	1210	312,94	5,539	5,777	1630	445,13	7,878	8,217
380	75,57	1,338	1,395	800	190,03	3,363	3,508	1220	316,02	5,593	5,833	1640	448,35	7,935	8,276
390	78,02	1,381	1,440	810	192,96	3,415	3,562	1230	319,09	5,648	5,890	1650	451,58	7,992	8,336
400	80,47	1,424	1,485	820	195,89	3,467	3,616	1240	322,18	5,702	5,947	1660	454,81	8,050	8,395
410	82,94	1,468	1,531	830	198,82	3,519	3,670	1250	325,26	5,757	6,004	1670	458,05	8,107	8,455
420	85,42	1,512	1,577	840	201,76	3,571	3,724	1260	328,35	5,811	6,061	1680	461,28	8,164	8,515
430	87,91	1,556	1,623	850	204,70	3,623	3,779	1270	331,44	5,866	6,118	1690	464,53	8,222	8,575
440	90,42	1,600	1,669	860	207,64	3,675	3,833	1280	334,53	5,921	6,175	1700	467,77	8,279	8,635
450	92,94	1,645	1,716	870	210,59	3,727	3,887	1290	337,63	5,976	6,232	1710	471,02	8,337	8,695
460	95,47	1,690	1,762	880	213,54	3,779	3,942	1300	340,73	6,031	6,290	1720	474,28	8,394	8,755
470	98,02	1,735	1,809	890	216,50	3,832	3,996	1310	343,84	6,086	6,347	1730	477,53	8,452	8,815
480	100,57	1,780	1,857	900	219,45	3,884	4,051	1320	346,95	6,141	6,404	1740	480,79	8,510	8,875
490	103,15	1,826	1,904	910	222,42	3,937	4,106	1330	350,06	6,196	6,462	1750	484,06	8,567	8,935
500	105,73	1,871	1,952	920	225,38	3,989	4,160	1340	353,18	6,251	6,519	1760	487,33	8,625	8,996
510	108,33	1,917	2,000	930	228,35	4,042	4,215	1350	356,30	6,306	6,577	1770	490,60	8,683	9,056
520	110,93	1,963	2,048	940	231,32	4,094	4,270	1360	359,42	6,361	6,635	1780	493,87	8,741	9,116
530	113,56	2,010	2,096	950	234,30	4,147	4,325	1370	362,55	6,417	6,692	1790	497,15	8,799	9,177
540	116,19	2,056	2,145	960	237,28	4,200	4,380	1380	365,68	6,472	6,750	1800	500,43	8,857	9,238
550	118,84	2,103	2,194	970	240,26	4,252	4,435	1390	368,82	6,528	6,808	1810	503,72	8,915	9,298
560	121,50	2,150	2,243	980	243,25	4,305	4,490	1400	371,95	6,583	6,866	1820	507,01	8,974	9,359
570	124,17	2,198	2,292	990	246,24	4,358	4,545	1410	375,10	6,639	6,924	1830	510,30	9,032	9,420
580	126,86	2,245	2,342	1000	249,23	4,411	4,601	1420	378,24	6,695	6,982	1840	513,60	9,090	9,481
590	129,56	2,293	2,392	1010	252,23	4,464	4,656	1430	381,39	6,750	7,040	1850	516,90	9,149	9,541
600	132,27	2,341	2,442	1020	255,23	4,517	4,711	1440	384,54	6,806	7,098	1860	520,20	9,207	9,602
610	135,13	2,392	2,494	1030	258,24	4,571	4,767	1450	387,70	6,862	7,157	1870	523,51	9,266	9,663
620	137,98	2,442	2,547	1040	261,25	4,624	4,822	1460	390,86	6,918	7,215	1880	526,82	9,324	9,725
630	140,85	2,493	2,600	1050	264,26	4,677	4,878	1470	394,02	6,974	7,273	1890	530,13	9,383	9,786
640	143,71	2,544	2,653	1060	267,28	4,731	4,934	1480	397,19	7,030	7,332	1900	533,45	9,442	9,847
650	146,58	2,594	2,706	1070	270,29	4,784	4,989	1490	400,36	7,086	7,390	1910	536,77	9,500	9,908
660	149,45	2,645	2,759	1080	273,32	4,837	5,045	1500	403,53	7,142	7,449	1920	540,10	9,559	9,970
670	152,33	2,696	2,812	1090	276,34	4,891	5,101	1510	406,71	7,198	7,508	1930	543,43	9,618	10,031
680	155,20	2,747	2,865	1100	279,37	4,945	5,157	1520	409,89	7,255	7,566	1940	546,76	9,677	10,093
690	158,09	2,798	2,918	1110	282,41	4,998	5,213	1530	413,08	7,311	7,625	1950	550,10	9,736	10,154
700	160,97	2,849	2,971	1120	285,45	5,052	5,269	1540	416,27	7,368	7,684	1960	553,44	9,795	10,216

$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$
1970	556,78	9,854	10,278	2380	696,95	12,335	12,865	2790	843,18	14,923	15,564	3200	995,45	17,618	18,375
1980	560,13	9,914	10,339	2390	700,45	12,397	12,930	2800	846,82	14,988	15,631	3210	999,24	17,686	18,445
1990	563,48	9,973	10,401	2400	703,95	12,459	12,994	2810	850,46	15,052	15,699	3220	1003,0	17,753	18,515
2000	566,83	10,032	10,463	2410	707,45	12,521	13,059	2820	854,11	15,117	15,766	3230	1006,8	17,820	18,585
2010	570,19	10,092	10,525	2420	710,95	12,583	13,124	2830	857,77	15,182	15,834	3240	1010,6	17,887	18,655
2020	573,55	10,151	10,587	2430	714,46	12,645	13,188	2840	861,42	15,246	15,901	3250	1014,4	17,954	18,725
2030	576,91	10,211	10,649	2440	717,97	12,707	13,253	2850	865,08	15,311	15,969	3260	1018,2	18,022	18,796
2040	580,28	10,270	10,711	2450	721,49	12,770	13,318	2860	868,75	15,376	16,036	3270	1022,1	18,089	18,866
2050	583,65	10,330	10,774	2460	725,01	12,832	13,383	2870	872,41	15,441	16,104	3280	1025,9	18,157	18,937
2060	587,03	10,390	10,836	2470	728,53	12,894	13,448	2880	876,08	15,506	16,172	3290	1029,7	18,224	19,007
2070	590,41	10,450	10,898	2480	732,06	12,957	13,513	2890	879,76	15,571	16,240	3300	1033,5	18,292	19,078
2080	593,79	10,510	10,961	2490	735,59	13,019	13,578	2900	883,44	15,636	16,307	3310	1037,3	18,360	19,148
2090	597,18	10,569	11,023	2500	739,12	13,082	13,644	2910	887,12	15,701	16,375	3320	1041,2	18,428	19,219
2100	600,57	10,629	11,086	2510	742,66	13,144	13,709	2920	890,80	15,766	16,443	3330	1045,0	18,495	19,290
2110	603,96	10,690	11,149	2520	746,20	13,207	13,774	2930	894,49	15,832	16,511	3340	1048,8	18,563	19,360
2120	607,36	10,750	11,211	2530	749,75	13,270	13,840	2940	898,18	15,897	16,580	3350	1052,7	18,631	19,431
2130	610,76	10,810	11,274	2540	753,30	13,333	13,905	2950	901,88	15,962	16,648	3360	1056,5	18,699	19,502
2140	614,17	10,870	11,337	2550	756,85	13,395	13,971	2960	905,58	16,028	16,716	3370	1060,4	18,767	19,573
2150	617,57	10,930	11,400	2560	760,40	13,458	14,036	2970	909,28	16,093	16,785	3380	1064,2	18,836	19,644
2160	620,99	10,991	11,463	2570	763,96	13,521	14,102	2980	912,99	16,159	16,853	3390	1068,1	18,904	19,716
2170	624,40	11,051	11,526	2580	767,53	13,584	14,168	2990	916,70	16,225	16,921	3400	1071,9	18,972	19,787
2180	627,82	11,112	11,589	2590	771,09	13,648	14,234	3000	920,41	16,290	16,990	3410	1075,8	19,040	19,858
2190	631,24	11,172	11,652	2600	774,66	13,711	14,300	3010	924,13	16,356	17,059	3420	1079,7	19,109	19,929
2200	634,67	11,233	11,715	2610	778,24	13,774	14,366	3020	927,85	16,422	17,127	3430	1083,5	19,177	20,001
2210	638,10	11,294	11,779	2620	781,81	13,837	14,432	3030	931,58	16,488	17,196	3440	1087,4	19,246	20,072
2220	641,53	11,354	11,842	2630	785,39	13,901	14,498	3040	935,31	16,554	17,265	3450	1091,3	19,314	20,144
2230	644,97	11,415	11,906	2640	788,98	13,964	14,564	3050	939,04	16,620	17,334	3460	1095,2	19,383	20,215
2240	648,41	11,476	11,969	2650	792,57	14,028	14,630	3060	942,77	16,686	17,403	3470	1099,0	19,452	20,287
2250	651,85	11,537	12,033	2660	796,16	14,091	14,696	3070	946,51	16,752	17,472	3480	1102,9	19,521	20,359
2260	655,30	11,598	12,096	2670	799,75	14,155	14,763	3080	950,26	16,819	17,541	3490	1106,8	19,589	20,431
2270	658,75	11,659	12,160	2680	803,35	14,219	14,829	3090	954,00	16,885	17,610	3500	1110,7	19,658	20,503
2280	662,21	11,720	12,224	2690	806,95	14,282	14,896	3100	957,75	16,951	17,679	3510	1114,6	19,727	20,574
2290	665,66	11,782	12,288	2700	810,56	14,346	14,962	3110	961,51	17,018	17,748	3520	1118,5	19,796	20,646
2300	669,13	11,843	12,351	2710	814,17	14,410	15,029	3120	965,26	17,084	17,818	3530	1122,4	19,865	20,719
2310	672,59	11,904	12,415	2720	817,78	14,474	15,096	3130	969,02	17,151	17,887	3540	1126,3	19,935	20,791
2320	676,06	11,966	12,479	2730	821,40	14,538	15,162	3140	972,79	17,217	17,957	3550	1130,2	20,004	20,863
2330	679,53	12,027	12,544	2740	825,02	14,602	15,229	3150	976,56	17,284	18,026	3560	1134,1	20,073	20,935
2340	683,01	12,089	12,608	2750	828,64	14,666	15,296	3160	980,33	17,351	18,096	3570	1138,1	20,143	21,008
2350	686,49	12,150	12,672	2760	832,27	14,730	15,363	3170	984,10	17,418	18,166	3580	1142,0	20,212	21,080
2360	689,97	12,212	12,736	2770	835,90	14,795	15,430	3180	987,88	17,485	18,235	3590	1145,9	20,281	21,152
2370	693,46	12,274	12,801	2780	839,54	14,859	15,497	3190	991,66	17,551	18,305	3600	1149,8	20,351	21,225

Lampe de Stefan-Boltzmann 1008523

Instructions d'utilisation

02/24 NF/ALF/UD



1. Consignes de sécurité

La lampe de Stefan-Boltzmann est conforme aux consignes de sécurité relatives aux appareils électriques de mesure, de commande et de régulation, ainsi qu'aux appareils de laboratoire, conformément à la norme DIN EN 61010 partie 1. Elle est conçue pour une utilisation dans des endroits secs adaptés aux matériels électriques.

Une utilisation conforme à la destination garantit un emploi de l'appareil en toute sécurité. La sécurité n'est cependant pas garantie si l'appareil fait l'objet d'un maniement inapproprié ou s'il est manipulé avec imprudence.

Attention : La lampe devra très chaude en service. Le contact avec la lampe peut engendrer un risque de brûlure ! En outre, les résidus de graisse risquent de cuire.

- Ne pas saisir la lampe avec les doigts.
- Une fois l'expérience terminée, laisser la lampe refroidir.

Précision :

Des tensions supérieures à 13 V risquent d'endommager le filament.

- Ne jamais brancher une tension supérieure à 13 V aux deux prises de 4 mm.

2 Description

La lampe de Stefan-Boltzmann est une source de chaleur à haute température avec un filament de Wolfram. Elle sert à la production de rayonnement thermique et à l'analyse de son évolution en fonction de la température, ou à la confirmation de la loi de Stefan-Boltzmann sous la forme

$$P = \varepsilon \cdot \sigma \cdot A \cdot T^4.$$

P étant la puissance rayonnée, T la température absolue du filament, A sa surface, σ la constante de Stefan-Boltzmann et ε une constante sans dimension entre 0 et 1. La température de la lampe est déterminée à partir de la résistance du serpentin de chauffage.

Le filament représente, à peu de choses près, une source de rayonnement en forme de point, et peut donc être utilisé dans l'étude de la loi de l'inverse du carré de la distance.

3. Contenu du colis

1 Lampe de Stefan-Boltzmann
1 Tige statif de 130 mm de long

4. Caractéristiques techniques

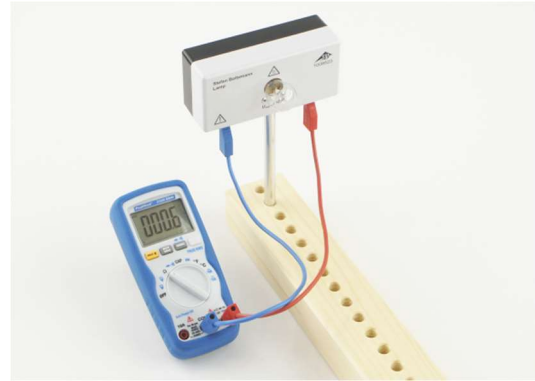
Tension nominale : 12 V CC
Courant nominal : 1,75 A
Puissance nominale : 21 W
Valeurs max. d'exploitation : 13 V CC / 2 A
Température maximale du filament : 3600 K
Distance entre le filament et la tige statif : 25 mm

5. Exemple de mesure

En plus nécessairement:

1 Thermopile d'après Moll 1000824
1 Alimentation CC 20 V, 5 A (@230V) 1003312
ou
1 Alimentation CC 20 V, 5 A (@115V) 1003311
1 Multimètre numérique P3340 1002785
2 Multimètres numériques P1035 1002781
2 Socles de serrage, 1000 g 1002834
1 Jeu de 15 cordons de sécurité, 75 cm 1002843

5.1 Mesure de la résistance du filament à température ambiante



- Insérer un cordon de mesure dans les prises COM et V Ω mA du multimètre numérique P3340 (1002785), et le court-circuiter.
- Ω -Sélectionner une plage, attendre que zéro s'affiche, puis appuyer brièvement sur la touche REL.
- Ouvrir le court-circuit des cordons de mesure et insérer les conducteurs dans les deux prises de la lampe de Stefan-Boltzmann.
- Lire et noter la valeur de résistance R_{ref} (Tab. 1)
- Retirer les cordons de mesure.
- Mesurer la température ambiante T_{ref} en plaçant la sonde thermique du multimètre à proximité de la lampe, et la noter en Kelvin (Tab. 1).

Tab. 1: Valeur de la résistance du filament mesurée à température ambiante

R_{ref}	0,541 Ω
T_{ref}	297 K

5.2 Mesure de l'intensité du rayonnement en fonction de la température du filament déterminée



- Raccorder la thermopile au multimètre numérique P3340 (1002785).
- Monter la lampe de Stefan-Boltzmann devant la thermopile et l'interconnecter avec l'alimentation CC et les deux multimètres numériques P1035 (1002781).
- Augmenter progressivement la tension U jusqu'à 12 V max. et mesurer la tension U et le courant I de la lampe et, à l'aide de la thermopile, l'intensité rayonnée Φ (5.3, Tab. 2).

5.3 Évaluation

- Calculer $R = U/I$ (Tab. 2).
- Avec les valeurs T_{ref} , R_{ref} , R déterminées et le coefficient de température de résistance $\alpha = 4,4 \cdot 10^{-3} \text{ K}^{-1}$ pour Wolfram, la température du filament peut être calculée (Tab. 2) selon la formule

$$T = \left(\frac{R - R_{\text{ref}}}{\alpha \cdot R_{\text{ref}}} \right) + T_{\text{ref}}$$

Il est également possible de déterminer la température T du filament en calculant les quotients R / R_{ref} et en déterminant la température à l'aide de Fig. 2 ou Tab. 3 en annexe.

Précision : Dans Tab. 3, le quotient R / R_{ref} est indiqué à la fois pour $T_{\text{ref}} = 300 \text{ K}$ et pour $T_{\text{ref}} = 290 \text{ K}$. Pour obtenir une évaluation plus précise, on peut interpoler entre ces valeurs, afin de tenir compte de la température ambiante réelle.

- Représenter Φ en fonction de T^4 (Fig. 3).

Tab. 2: Valeurs de la résistance R et de la température T du filament calculées à partir des valeurs mesurées pour la tension U du filament et le courant I de la lampe ainsi que l'intensité rayonnée Φ mesurée par la thermopile

U / V	I / A	R / Ω	T / K	Φ / W
0,00369	0,006	0,615	328	0
1,0502	0,554	1,896	854	0,0001
2,033	0,706	2,879	1259	0,0004
3,012	0,837	3,599	1554	0,0011
4,003	0,958	4,178	1792	0,0019
5,012	1,071	4,679	1998	0,0029
6,017	1,174	5,125	2181	0,0042
7,074	1,276	5,5434	2353	0,0058
8,028	1,362	5,894	2497	0,0072
9,011	1,446	6,232	2636	0,0088
10,088	1,534	6,576	2777	0,0106
11,02	1,607	6,8575	2893	0,0125
11,685	1,68	6,955	2933	0,0145

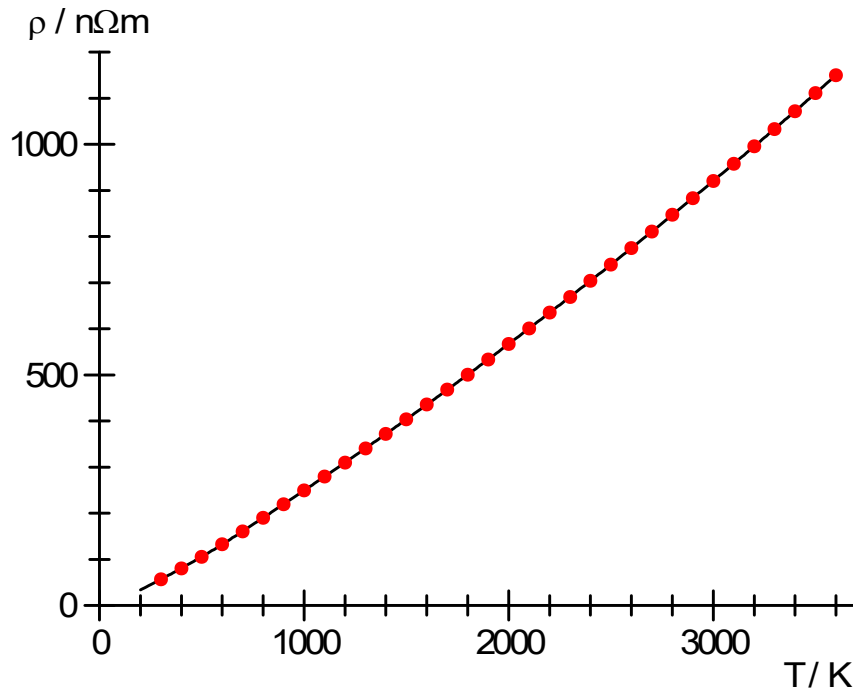


Fig. 1: Résistance spécifique ρ de Wolfram en fonction de la température absolue T (cf. Tab. 3). Courbe adaptée aux valeurs de mesure de Zerda, T.W., Texas Christian University. 2001

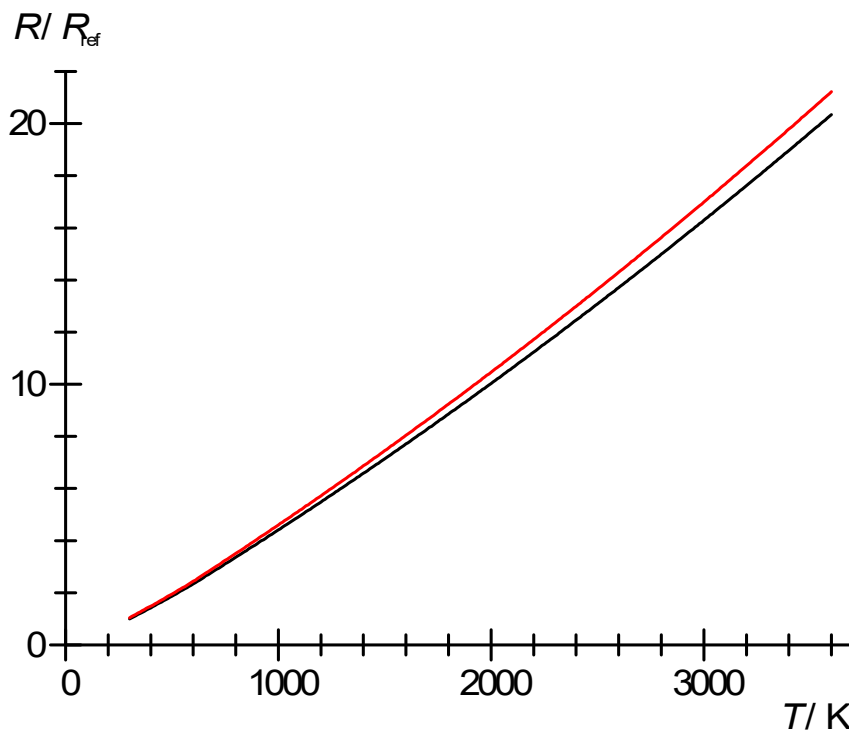


Fig. 2: Taux de résistance $R(T) / R_{300\text{K}}$ (noir) ou $R(T) / R_{290\text{K}}$ (rouge) calculé à partir des valeurs représentées sur Fig. 1 (cf. Tab. 3)

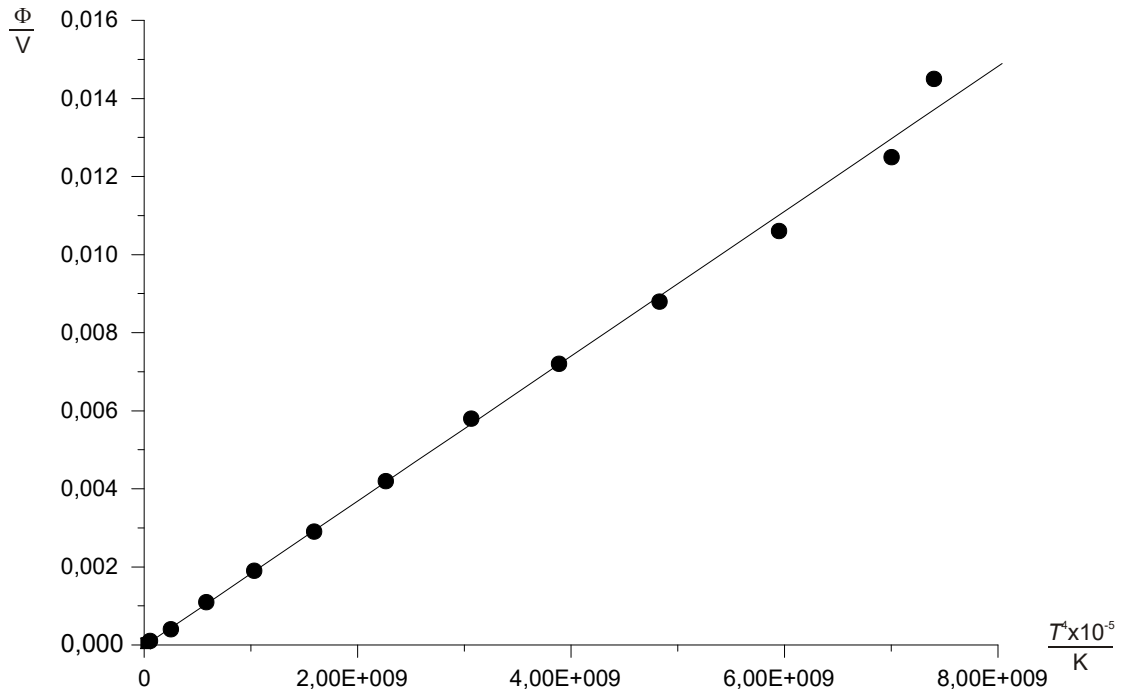


Fig. 3: Intensité du rayonnement Φ en fonction de la température T

6 Remplacement de la lampe

Pour remplacer la lampe, les outils suivants sont également nécessaires :

1 Lampe 12 V / 21 W, socle BA15S

1 tournevis

1 papier émeri

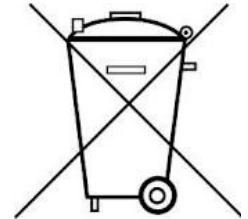
1 fer à souder

Étain

- Dévisser la coque arrière du boîtier.
- Dessouder la lampe.
- Poncer et étamer la lampe à l'aide d'un papier émeri, aux endroits où le fil sera soudé.
- Positionner la lampe et la souder.
- Tester la lampe avec une tension de 12V.
- Revisser le boîtier.

7. Traitement des déchets

- L'emballage doit être déposé aux centres de recyclage locaux.
- Si l'appareil doit être jeté, ne pas le jeter dans les ordures ménagères. Il est important de respecter les consignes locales relatives au traitement des déchets électriques.



8. Annexe

Tab. 3 Résistance spécifique ρ de Wolfram en fonction de la température absolue T et taux de résistance en résultant $R(T) / R_{300K}$ ou $R(T) / R_{290K}$ (cf. Fig. 1 et Fig. 2)

$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$
290	54,17		1,000	710	163,86	2,900	3,025	1130	288,49	5,106	5,325	1550	419,46	7,424	7,743
300	56,50	1,000	1,043	720	166,76	2,951	3,078	1140	291,53	5,160	5,381	1560	422,65	7,481	7,802
310	58,84	1,041	1,086	730	169,65	3,003	3,132	1150	294,58	5,214	5,438	1570	425,85	7,537	7,861
320	61,19	1,083	1,130	740	172,55	3,054	3,185	1160	297,63	5,268	5,494	1580	429,06	7,594	7,920
330	63,56	1,125	1,173	750	175,46	3,105	3,239	1170	300,69	5,322	5,550	1590	432,26	7,651	7,979

340	65,93	1,167	1,217	760	178,37	3,157	3,292	1180	303,75	5,376	5,607	1600	435,47	7,707	8,038
350	68,33	1,209	1,261	770	181,28	3,208	3,346	1190	306,81	5,430	5,663	1610	438,69	7,764	8,098
360	70,73	1,252	1,306	780	184,19	3,260	3,400	1200	309,87	5,484	5,720	1620	441,90	7,821	8,157
370	73,14	1,295	1,350	790	187,11	3,312	3,454	1210	312,94	5,539	5,777	1630	445,13	7,878	8,217
380	75,57	1,338	1,395	800	190,03	3,363	3,508	1220	316,02	5,593	5,833	1640	448,35	7,935	8,276
390	78,02	1,381	1,440	810	192,96	3,415	3,562	1230	319,09	5,648	5,890	1650	451,58	7,992	8,336
400	80,47	1,424	1,485	820	195,89	3,467	3,616	1240	322,18	5,702	5,947	1660	454,81	8,050	8,395
410	82,94	1,468	1,531	830	198,82	3,519	3,670	1250	325,26	5,757	6,004	1670	458,05	8,107	8,455
420	85,42	1,512	1,577	840	201,76	3,571	3,724	1260	328,35	5,811	6,061	1680	461,28	8,164	8,515
430	87,91	1,556	1,623	850	204,70	3,623	3,779	1270	331,44	5,866	6,118	1690	464,53	8,222	8,575
440	90,42	1,600	1,669	860	207,64	3,675	3,833	1280	334,53	5,921	6,175	1700	467,77	8,279	8,635
450	92,94	1,645	1,716	870	210,59	3,727	3,887	1290	337,63	5,976	6,232	1710	471,02	8,337	8,695
460	95,47	1,690	1,762	880	213,54	3,779	3,942	1300	340,73	6,031	6,290	1720	474,28	8,394	8,755
470	98,02	1,735	1,809	890	216,50	3,832	3,996	1310	343,84	6,086	6,347	1730	477,53	8,452	8,815
480	100,57	1,780	1,857	900	219,45	3,884	4,051	1320	346,95	6,141	6,404	1740	480,79	8,510	8,875
490	103,15	1,826	1,904	910	222,42	3,937	4,106	1330	350,06	6,196	6,462	1750	484,06	8,567	8,935
500	105,73	1,871	1,952	920	225,38	3,989	4,160	1340	353,18	6,251	6,519	1760	487,33	8,625	8,996
510	108,33	1,917	2,000	930	228,35	4,042	4,215	1350	356,30	6,306	6,577	1770	490,60	8,683	9,056
520	110,93	1,963	2,048	940	231,32	4,094	4,270	1360	359,42	6,361	6,635	1780	493,87	8,741	9,116
530	113,56	2,010	2,096	950	234,30	4,147	4,325	1370	362,55	6,417	6,692	1790	497,15	8,799	9,177
540	116,19	2,056	2,145	960	237,28	4,200	4,380	1380	365,68	6,472	6,750	1800	500,43	8,857	9,238
550	118,84	2,103	2,194	970	240,26	4,252	4,435	1390	368,82	6,528	6,808	1810	503,72	8,915	9,298
560	121,50	2,150	2,243	980	243,25	4,305	4,490	1400	371,95	6,583	6,866	1820	507,01	8,974	9,359
570	124,17	2,198	2,292	990	246,24	4,358	4,545	1410	375,10	6,639	6,924	1830	510,30	9,032	9,420
580	126,86	2,245	2,342	1000	249,23	4,411	4,601	1420	378,24	6,695	6,982	1840	513,60	9,090	9,481
590	129,56	2,293	2,392	1010	252,23	4,464	4,656	1430	381,39	6,750	7,040	1850	516,90	9,149	9,541
600	132,27	2,341	2,442	1020	255,23	4,517	4,711	1440	384,54	6,806	7,098	1860	520,20	9,207	9,602
610	135,13	2,392	2,494	1030	258,24	4,571	4,767	1450	387,70	6,862	7,157	1870	523,51	9,266	9,663
620	137,98	2,442	2,547	1040	261,25	4,624	4,822	1460	390,86	6,918	7,215	1880	526,82	9,324	9,725
630	140,85	2,493	2,600	1050	264,26	4,677	4,878	1470	394,02	6,974	7,273	1890	530,13	9,383	9,786
640	143,71	2,544	2,653	1060	267,28	4,731	4,934	1480	397,19	7,030	7,332	1900	533,45	9,442	9,847
650	146,58	2,594	2,706	1070	270,29	4,784	4,989	1490	400,36	7,086	7,390	1910	536,77	9,500	9,908
660	149,45	2,645	2,759	1080	273,32	4,837	5,045	1500	403,53	7,142	7,449	1920	540,10	9,559	9,970
670	152,33	2,696	2,812	1090	276,34	4,891	5,101	1510	406,71	7,198	7,508	1930	543,43	9,618	10,031
680	155,20	2,747	2,865	1100	279,37	4,945	5,157	1520	409,89	7,255	7,566	1940	546,76	9,677	10,093
690	158,09	2,798	2,918	1110	282,41	4,998	5,213	1530	413,08	7,311	7,625	1950	550,10	9,736	10,154
700	160,97	2,849	2,971	1120	285,45	5,052	5,269	1540	416,27	7,368	7,684	1960	553,44	9,795	10,216

$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$
1970	556,78	9,854	10,278	2380	696,95	12,335	12,865	2790	843,18	14,923	15,564	3200	995,45	17,618	18,375
1980	560,13	9,914	10,339	2390	700,45	12,397	12,930	2800	846,82	14,988	15,631	3210	999,24	17,686	18,445
1990	563,48	9,973	10,401	2400	703,95	12,459	12,994	2810	850,46	15,052	15,699	3220	1003,0	17,753	18,515
2000	566,83	10,032	10,463	2410	707,45	12,521	13,059	2820	854,11	15,117	15,766	3230	1006,8	17,820	18,585
2010	570,19	10,092	10,525	2420	710,95	12,583	13,124	2830	857,77	15,182	15,834	3240	1010,6	17,887	18,655
2020	573,55	10,151	10,587	2430	714,46	12,645	13,188	2840	861,42	15,246	15,901	3250	1014,4	17,954	18,725
2030	576,91	10,211	10,649	2440	717,97	12,707	13,253	2850	865,08	15,311	15,969	3260	1018,2	18,022	18,796
2040	580,28	10,270	10,711	2450	721,49	12,770	13,318	2860	868,75	15,376	16,036	3270	1022,1	18,089	18,866
2050	583,65	10,330	10,774	2460	725,01	12,832	13,383	2870	872,41	15,441	16,104	3280	1025,9	18,157	18,937
2060	587,03	10,390	10,836	2470	728,53	12,894	13,448	2880	876,08	15,506	16,172	3290	1029,7	18,224	19,007
2070	590,41	10,450	10,898	2480	732,06	12,957	13,513	2890	879,76	15,571	16,240	3300	1033,5	18,292	19,078
2080	593,79	10,510	10,961	2490	735,59	13,019	13,578	2900	883,44	15,636	16,307	3310	1037,3	18,360	19,148
2090	597,18	10,569	11,023	2500	739,12	13,082	13,644	2910	887,12	15,701	16,375	3320	1041,2	18,428	19,219
2100	600,57	10,629	11,086	2510	742,66	13,144	13,709	2920	890,80	15,766	16,443	3330	1045,0	18,495	19,290
2110	603,96	10,690	11,149	2520	746,20	13,207	13,774	2930	894,49	15,832	16,511	3340	1048,8	18,563	19,360
2120	607,36	10,750	11,211	2530	749,75	13,270	13,840	2940	898,18	15,897	16,580	3350	1052,7	18,631	19,431
2130	610,76	10,810	11,274	2540	753,30	13,333	13,905	2950	901,88	15,962	16,648	3360	1056,5	18,699	19,502
2140	614,17	10,870	11,337	2550	756,85	13,395	13,971	2960	905,58	16,028	16,716	3370	1060,4	18,767	19,573
2150	617,57	10,930	11,400	2560	760,40	13,458	14,036	2970	909,28	16,093	16,785	3380	1064,2	18,836	19,644
2160	620,99	10,991	11,463	2570	763,96	13,521	14,102	2980	912,99	16,159	16,853	3390	1068,1	18,904	19,716
2170	624,40	11,051	11,526	2580	767,53	13,584	14,168	2990	916,70	16,225	16,921	3400	1071,9	18,972	19,787
2180	627,82	11,112	11,589	2590	771,09	13,648	14,234	3000	920,41	16,290	16,990	3410	1075,8	19,040	19,858
2190	631,24	11,172	11,652	2600	774,66	13,711	14,300	3010	924,13	16,356	17,059	3420	1079,7	19,109	19,929
2200	634,67	11,233	11,715	2610	778,24	13,774	14,366	3020	927,85	16,422	17,127	3430	1083,5	19,177	20,001
2210	638,10	11,294	11,779	2620	781,81	13,837	14,432	3030	931,58	16,488	17,196	3440	1087,4	19,246	20,072
2220	641,53	11,354	11,842	2630	785,39	13,901	14,498	3040	935,31	16,554	17,265	3450	1091,3	19,314	20,144
2230	644,97	11,415	11,906	2640	788,98	13,964	14,564	3050	939,04	16,620	17,334	3460	1095,2	19,383	20,215
2240	648,41	11,476	11,969	2650	792,57	14,028	14,630	3060	942,77	16,686	17,403	3470	1099,0	19,452	20,287
2250	651,85	11,537	12,033	2660	796,16	14,091	14,696	3070	946,51	16,752	17,472	3480	1102,9	19,521	20,359
2260	655,30	11,598	12,096	2670	799,75	14,155	14,763	3080	950,26	16,819	17,541	3490	1106,8	19,589	20,431
2270	658,75	11,659	12,160	2680	803,35	14,219	14,829	3090	954,00	16,885	17,610	3500	1110,7	19,658	20,503
2280	662,21	11,720	12,224	2690	806,95	14,282	14,896	3100	957,75	16,951	17,679	3510	1114,6	19,727	20,574
2290	665,66	11,782	12,288	2700	810,56	14,346	14,962	3110	961,51	17,018	17,748	3520	1118,5	19,796	20,646
2300	669,13	11,843	12,351	2710	814,17	14,410	15,029	3120	965,26	17,084	17,818	3530	1122,4	19,865	20,719
2310	672,59	11,904	12,415	2720	817,78	14,474	15,096	3130	969,02	17,151	17,887	3540	1126,3	19,935	20,791
2320	676,06	11,966	12,479	2730	821,40	14,538	15,162	3140	972,79	17,217	17,957	3550	1130,2	20,004	20,863
2330	679,53	12,027	12,544	2740	825,02	14,602	15,229	3150	976,56	17,284	18,026	3560	1134,1	20,073	20,935
2340	683,01	12,089	12,608	2750	828,64	14,666	15,296	3160	980,33	17,351	18,096	3570	1138,1	20,143	21,008
2350	686,49	12,150	12,672	2760	832,27	14,730	15,363	3170	984,10	17,418	18,166	3580	1142,0	20,212	21,080
2360	689,97	12,212	12,736	2770	835,90	14,795	15,430	3180	987,88	17,485	18,235	3590	1145,9	20,281	21,152
2370	693,46	12,274	12,801	2780	839,54	14,859	15,497	3190	991,66	17,551	18,305	3600	1149,8	20,351	21,225

Lampada di Stefan-Boltzmann 1008523

Istruzioni per l'uso

02/24 NF/ALF/UD



1. Avvertenze per la sicurezza

La lampada di Stefan-Boltzmann risponde alle disposizioni di sicurezza per apparecchi elettrici di misura, di comando, di regolazione e da laboratorio della norma DIN EN 61010 Parte 1 ed è pensata per l'utilizzo in ambienti asciutti, adatti per strumenti elettrici.

Un utilizzo conforme garantisce il funzionamento sicuro della dotazione. La sicurezza non è tuttavia garantita se gli apparecchi non vengono utilizzati in modo appropriato o trattati con cura.

Attenzione: Durante il funzionamento, la lampada si riscalda notevolmente. Pericolo di ustioni in caso di contatto! Residui di grasso potrebbero inoltre aderire alla superficie.

- Non toccare la lampada con le dita.
- Al termine dell'esperimento lasciare raffreddare la lampada.

Nota:

Con tensioni di allacciamento superiori ai 13 V il filamento si distrugge.

- Non collegare mai ai due jack da 4 mm una tensione superiore ai 13 V.

2. Descrizione

La lampada di Stefan-Boltzmann è una sorgente di alte temperature con un filamento al tungsteno. Essa serve per la generazione di radiazione termica e per esaminare la sua dipendenza della temperatura o per confermare la legge di Stefan-Boltzmann nella formulazione.

$$P = \varepsilon \cdot \sigma \cdot A \cdot T^4.$$

P è la potenza emessa, T la temperatura assoluta del filamento, A la sua superficie, σ la costante di Stefan-Boltzmann e ε una costante senza dimensione tra 0 e 1. La temperatura della lampada viene calcolata a partire dalla resistenza della spirale di riscaldamento.

Il filamento rappresenta con buona approssimazione una sorgente di irradiazione puntiforme ed è quindi adatto anche per esaminare la legge dell'inverso del quadrato della distanza.

3. Dotazione

1 Lampada di Stefan-Boltzmann
1 Supporto stativo, 130 mm di lunghezza

4. Dati tecnici

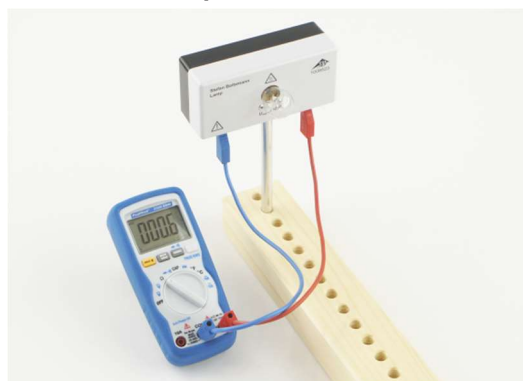
Tensione nominale:	12 V CC
Corrente nominale:	1,75 A
Potenza nominale:	21 W
Valori massimi di esercizio:	13 V CC / 2 A
Temperatura massima del filamento:	3600 K
Distanza del filamento dal supporto stativo:	25 mm

5. Esempio di misurazione

Ulteriormente necessario:

1 Termopila di Moll	1000824
1 Alimentatore CC 20 V, 5 A (@230V)	1003312
oppure	
1 Alimentatore CC 20 V, 5 A (@115V)	1003311
1 Multimetro digitale P3340	1002785
2 Multimetri digitali P1035	1002781
2 Piedi a barilotto, 1000 g	1002834
1 Set di 15 cavi di sicurezza per esperimenti, 75 cm	1002843

5.1 Misurazione della resistenza del filamento a temperatura ambiente



- Inserire una linea di misura nel jack COM e una nel jack V Ω mA del multimetro digitale P3340 (1002785) e mettere in cortocircuito.
- Selezionare il campo Ω , attendere che il display indichi zero, infine premere brevemente il tasto REL.
- Aprire il cortocircuito delle linee di misura e inserire la linea nei due jack della lampada di Stefan-Boltzmann.
- Leggere il valore della resistenza R_{ref} e annotarlo (Tab. 1).
- Rimuovere le linee di misura.
- Con il sensore termico del multimetro vicino alla lampada, misurare la temperatura dell'ambiente T_{ref} in Kelvin e annotarla (Tab. 1).

Tab. 1: Valore della resistenza del filamento misurato a temperatura ambiente

R_{ref}	0,541 Ω
T_{ref}	297 K

5.2 Misurazione dell'intensità delle radiazioni in funzione della temperatura del filamento rilevata



- Collegare la termopila al multimetro digitale P3340 (1002785).
- Montare la lampada di Stefan-Boltzmann davanti alla termopila e collegarla all'alimentatore CC e ai due multimetri digitali P1035 (1002781).
- Impostare la tensione U da 1 V a massimo 12 V e misurare la tensione della lampada U , la corrente della lampada I e, con la termopila, l'intensità emessa Φ (5.3, Tab. 2).

5.3 Analisi

- Calcolare $R = U/I$ (Tab. 2).
- Con i valori rilevati T_{ref} , R_{ref} , R e il coefficiente di temperatura della resistenza $\alpha = 4,4 \cdot 10^{-3} \text{ K}^{-1}$ per il tungsteno è possibile calcolare la temperatura del filamento (Tab. 2) secondo la formula

$$T = \left(\frac{R - R_{\text{ref}}}{\alpha \cdot R_{\text{ref}}} \right) + T_{\text{ref}} .$$

Una possibile alternativa per determinare la temperatura T del filamento consiste nel calcolare il quoziente R / R_{ref} e da esso, con l'ausilio di Fig. 2 risp. Tab. 3 nell'appendice, rilevare la temperatura.

Nota: Nella Tab. 3, il quoziente R / R_{ref} è indicato sia per $T_{\text{ref}} = 300 \text{ K}$ sia per $T_{\text{ref}} = 290 \text{ K}$. Per un'analisi più precisa è possibile interpolare tra questi valori, per considerare la temperatura ambiente effettiva.

- Rappresentare Φ in funzione di T^4 (Fig. 3).

Tab. 2: Valori della resistenza R e della temperatura T del filamento calcolato dai valori per la tensione della lampada U e la corrente della lampada I e l'intensità emessa Φ misurata con la termopila

U / V	I / A	R / Ω	T / K	Φ / V
0,00369	0,006	0,615	328	0
1,0502	0,554	1,896	854	0,0001
2,033	0,706	2,879	1259	0,0004
3,012	0,837	3,599	1554	0,0011
4,003	0,958	4,178	1792	0,0019
5,012	1,071	4,679	1998	0,0029
6,017	1,174	5,125	2181	0,0042
7,074	1,276	5,5434	2353	0,0058
8,028	1,362	5,894	2497	0,0072
9,011	1,446	6,232	2636	0,0088
10,088	1,534	6,576	2777	0,0106
11,02	1,607	6,8575	2893	0,0125
11,685	1,68	6,955	2933	0,0145

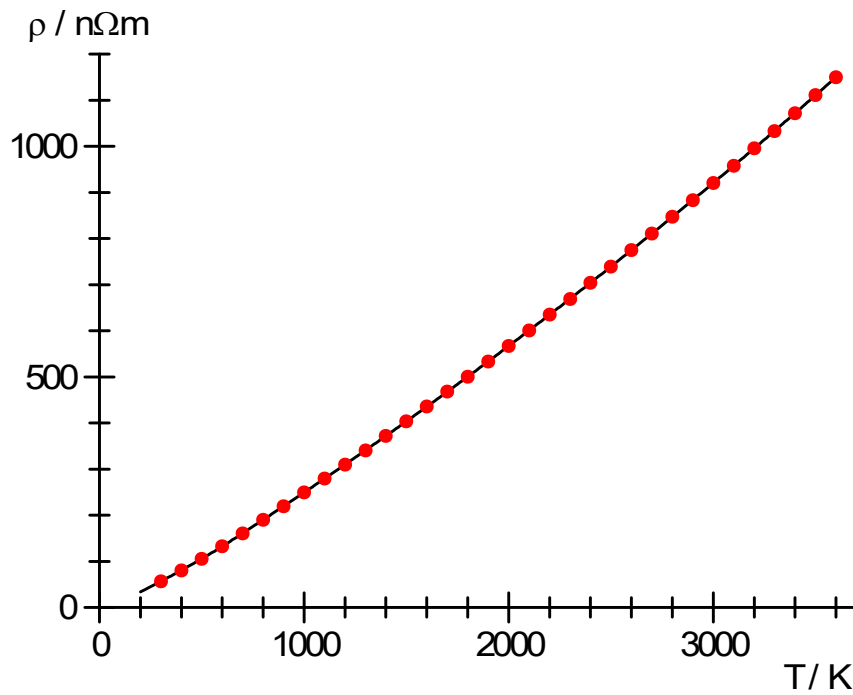


Fig. 1: Resistenza specifica ρ del tungsteno in funzione della temperatura assoluta T (cfr. Tab. 3). Curva adattata ai valori di misurazione di Zerda, T.W., Texas Christian University, 2001

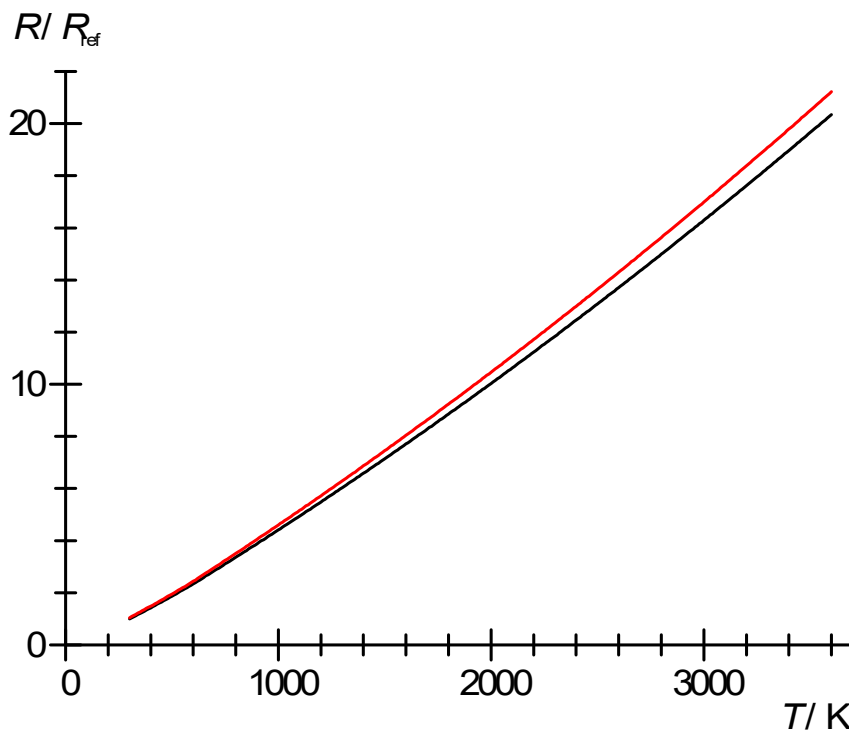


Fig. 2: Rapporti di resistenza $R(T) / R_{300 K}$ (nero) e $R(T) / R_{290 K}$ (rosso) (cfr. Tab. 3) calcolati sulla base dei valori di cui al Fig. 1

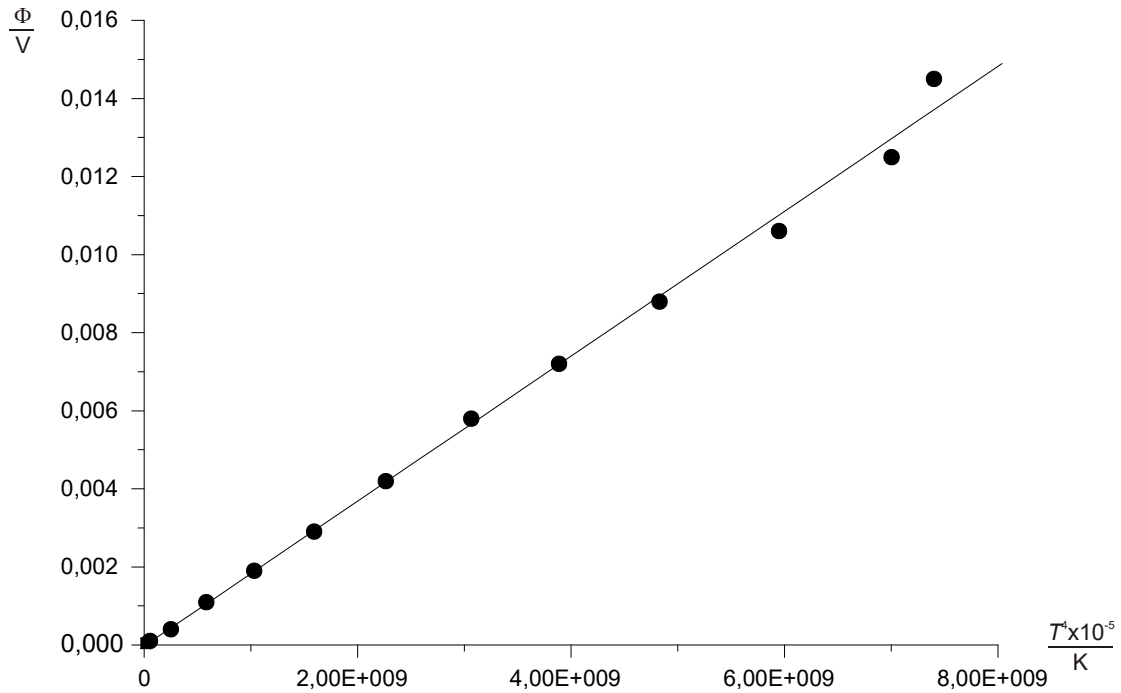


Fig. 3: Intensità delle radiazioni Φ in funzione della temperatura T

6. Sostituzione della lampada

Per sostituire la lampada occorrono inoltre i seguenti utensili:

1 lampada 12 V / 21 W, base BA15S

1 cacciavite

1 carta vetrata

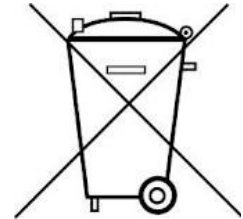
1 saldatoio

Stagno

- Svitare la parete dell'alloggiamento.
- Dissaldare la lampada.
- Smerigliare la nuova lampada nei punti dove il filo verrà saldato e stagnare.
- Introdurre la lampada e saldare.
- Testare la lampada a 12 V.
- Riavvitare l'alloggiamento.

7. Smaltimento

- Smaltire l'imballo presso i centri di raccolta e riciclaggio locali.
- Non gettare l'apparecchio nei rifiuti domestici. Per lo smaltimento delle apparecchiature elettriche, rispettare le disposizioni vigenti a livello locale.



8. Appendice

Tab. 3 Resistenza specifica ρ del tungsteno in funzione della temperatura assoluta T e rapporti di resistenza $R(T) / R_{300K}$ o $R(T) / R_{290K}$ calcolati da essa (cfr. Fig. 1 e Fig. 2)

T K	ρ n Ω m	$R(T)$ R_{300K}	$R(T)$ R_{290K}	T K	ρ n Ω m	$R(T)$ R_{300K}	$R(T)$ R_{290K}	T K	ρ n Ω m	$R(T)$ R_{300K}	$R(T)$ R_{290K}	T K	ρ n Ω m	$R(T)$ R_{300K}	$R(T)$ R_{290K}
290	54,17	1,000		710	163,86	2,900	3,025	1130	288,49	5,106	5,325	1550	419,46	7,424	7,743
300	56,50	1,000	1,043	720	166,76	2,951	3,078	1140	291,53	5,160	5,381	1560	422,65	7,481	7,802
310	58,84	1,041	1,086	730	169,65	3,003	3,132	1150	294,58	5,214	5,438	1570	425,85	7,537	7,861
320	61,19	1,083	1,130	740	172,55	3,054	3,185	1160	297,63	5,268	5,494	1580	429,06	7,594	7,920

330	63,56	1,125	1,173	750	175,46	3,105	3,239	1170	300,69	5,322	5,550	1590	432,26	7,651	7,979
340	65,93	1,167	1,217	760	178,37	3,157	3,292	1180	303,75	5,376	5,607	1600	435,47	7,707	8,038
350	68,33	1,209	1,261	770	181,28	3,208	3,346	1190	306,81	5,430	5,663	1610	438,69	7,764	8,098
360	70,73	1,252	1,306	780	184,19	3,260	3,400	1200	309,87	5,484	5,720	1620	441,90	7,821	8,157
370	73,14	1,295	1,350	790	187,11	3,312	3,454	1210	312,94	5,539	5,777	1630	445,13	7,878	8,217
380	75,57	1,338	1,395	800	190,03	3,363	3,508	1220	316,02	5,593	5,833	1640	448,35	7,935	8,276
390	78,02	1,381	1,440	810	192,96	3,415	3,562	1230	319,09	5,648	5,890	1650	451,58	7,992	8,336
400	80,47	1,424	1,485	820	195,89	3,467	3,616	1240	322,18	5,702	5,947	1660	454,81	8,050	8,395
410	82,94	1,468	1,531	830	198,82	3,519	3,670	1250	325,26	5,757	6,004	1670	458,05	8,107	8,455
420	85,42	1,512	1,577	840	201,76	3,571	3,724	1260	328,35	5,811	6,061	1680	461,28	8,164	8,515
430	87,91	1,556	1,623	850	204,70	3,623	3,779	1270	331,44	5,866	6,118	1690	464,53	8,222	8,575
440	90,42	1,600	1,669	860	207,64	3,675	3,833	1280	334,53	5,921	6,175	1700	467,77	8,279	8,635
450	92,94	1,645	1,716	870	210,59	3,727	3,887	1290	337,63	5,976	6,232	1710	471,02	8,337	8,695
460	95,47	1,690	1,762	880	213,54	3,779	3,942	1300	340,73	6,031	6,290	1720	474,28	8,394	8,755
470	98,02	1,735	1,809	890	216,50	3,832	3,996	1310	343,84	6,086	6,347	1730	477,53	8,452	8,815
480	100,57	1,780	1,857	900	219,45	3,884	4,051	1320	346,95	6,141	6,404	1740	480,79	8,510	8,875
490	103,15	1,826	1,904	910	222,42	3,937	4,106	1330	350,06	6,196	6,462	1750	484,06	8,567	8,935
500	105,73	1,871	1,952	920	225,38	3,989	4,160	1340	353,18	6,251	6,519	1760	487,33	8,625	8,996
510	108,33	1,917	2,000	930	228,35	4,042	4,215	1350	356,30	6,306	6,577	1770	490,60	8,683	9,056
520	110,93	1,963	2,048	940	231,32	4,094	4,270	1360	359,42	6,361	6,635	1780	493,87	8,741	9,116
530	113,56	2,010	2,096	950	234,30	4,147	4,325	1370	362,55	6,417	6,692	1790	497,15	8,799	9,177
540	116,19	2,056	2,145	960	237,28	4,200	4,380	1380	365,68	6,472	6,750	1800	500,43	8,857	9,238
550	118,84	2,103	2,194	970	240,26	4,252	4,435	1390	368,82	6,528	6,808	1810	503,72	8,915	9,298
560	121,50	2,150	2,243	980	243,25	4,305	4,490	1400	371,95	6,583	6,866	1820	507,01	8,974	9,359
570	124,17	2,198	2,292	990	246,24	4,358	4,545	1410	375,10	6,639	6,924	1830	510,30	9,032	9,420
580	126,86	2,245	2,342	1000	249,23	4,411	4,601	1420	378,24	6,695	6,982	1840	513,60	9,090	9,481
590	129,56	2,293	2,392	1010	252,23	4,464	4,656	1430	381,39	6,750	7,040	1850	516,90	9,149	9,541
600	132,27	2,341	2,442	1020	255,23	4,517	4,711	1440	384,54	6,806	7,098	1860	520,20	9,207	9,602
610	135,13	2,392	2,494	1030	258,24	4,571	4,767	1450	387,70	6,862	7,157	1870	523,51	9,266	9,663
620	137,98	2,442	2,547	1040	261,25	4,624	4,822	1460	390,86	6,918	7,215	1880	526,82	9,324	9,725
630	140,85	2,493	2,600	1050	264,26	4,677	4,878	1470	394,02	6,974	7,273	1890	530,13	9,383	9,786
640	143,71	2,544	2,653	1060	267,28	4,731	4,934	1480	397,19	7,030	7,332	1900	533,45	9,442	9,847
650	146,58	2,594	2,706	1070	270,29	4,784	4,989	1490	400,36	7,086	7,390	1910	536,77	9,500	9,908
660	149,45	2,645	2,759	1080	273,32	4,837	5,045	1500	403,53	7,142	7,449	1920	540,10	9,559	9,970
670	152,33	2,696	2,812	1090	276,34	4,891	5,101	1510	406,71	7,198	7,508	1930	543,43	9,618	10,031
680	155,20	2,747	2,865	1100	279,37	4,945	5,157	1520	409,89	7,255	7,566	1940	546,76	9,677	10,093
690	158,09	2,798	2,918	1110	282,41	4,998	5,213	1530	413,08	7,311	7,625	1950	550,10	9,736	10,154
700	160,97	2,849	2,971	1120	285,45	5,052	5,269	1540	416,27	7,368	7,684	1960	553,44	9,795	10,216

$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$
1970	556,78	9,854	10,278	2380	696,95	12,335	12,865	2790	843,18	14,923	15,564	3200	995,45	17,618	18,375
1980	560,13	9,914	10,339	2390	700,45	12,397	12,930	2800	846,82	14,988	15,631	3210	999,24	17,686	18,445
1990	563,48	9,973	10,401	2400	703,95	12,459	12,994	2810	850,46	15,052	15,699	3220	1003,0	17,753	18,515
2000	566,83	10,032	10,463	2410	707,45	12,521	13,059	2820	854,11	15,117	15,766	3230	1006,8	17,820	18,585
2010	570,19	10,092	10,525	2420	710,95	12,583	13,124	2830	857,77	15,182	15,834	3240	1010,6	17,887	18,655
2020	573,55	10,151	10,587	2430	714,46	12,645	13,188	2840	861,42	15,246	15,901	3250	1014,4	17,954	18,725
2030	576,91	10,211	10,649	2440	717,97	12,707	13,253	2850	865,08	15,311	15,969	3260	1018,2	18,022	18,796
2040	580,28	10,270	10,711	2450	721,49	12,770	13,318	2860	868,75	15,376	16,036	3270	1022,1	18,089	18,866
2050	583,65	10,330	10,774	2460	725,01	12,832	13,383	2870	872,41	15,441	16,104	3280	1025,9	18,157	18,937
2060	587,03	10,390	10,836	2470	728,53	12,894	13,448	2880	876,08	15,506	16,172	3290	1029,7	18,224	19,007
2070	590,41	10,450	10,898	2480	732,06	12,957	13,513	2890	879,76	15,571	16,240	3300	1033,5	18,292	19,078
2080	593,79	10,510	10,961	2490	735,59	13,019	13,578	2900	883,44	15,636	16,307	3310	1037,3	18,360	19,148
2090	597,18	10,569	11,023	2500	739,12	13,082	13,644	2910	887,12	15,701	16,375	3320	1041,2	18,428	19,219
2100	600,57	10,629	11,086	2510	742,66	13,144	13,709	2920	890,80	15,766	16,443	3330	1045,0	18,495	19,290
2110	603,96	10,690	11,149	2520	746,20	13,207	13,774	2930	894,49	15,832	16,511	3340	1048,8	18,563	19,360
2120	607,36	10,750	11,211	2530	749,75	13,270	13,840	2940	898,18	15,897	16,580	3350	1052,7	18,631	19,431
2130	610,76	10,810	11,274	2540	753,30	13,333	13,905	2950	901,88	15,962	16,648	3360	1056,5	18,699	19,502
2140	614,17	10,870	11,337	2550	756,85	13,395	13,971	2960	905,58	16,028	16,716	3370	1060,4	18,767	19,573
2150	617,57	10,930	11,400	2560	760,40	13,458	14,036	2970	909,28	16,093	16,785	3380	1064,2	18,836	19,644
2160	620,99	10,991	11,463	2570	763,96	13,521	14,102	2980	912,99	16,159	16,853	3390	1068,1	18,904	19,716
2170	624,40	11,051	11,526	2580	767,53	13,584	14,168	2990	916,70	16,225	16,921	3400	1071,9	18,972	19,787
2180	627,82	11,112	11,589	2590	771,09	13,648	14,234	3000	920,41	16,290	16,990	3410	1075,8	19,040	19,858
2190	631,24	11,172	11,652	2600	774,66	13,711	14,300	3010	924,13	16,356	17,059	3420	1079,7	19,109	19,929
2200	634,67	11,233	11,715	2610	778,24	13,774	14,366	3020	927,85	16,422	17,127	3430	1083,5	19,177	20,001
2210	638,10	11,294	11,779	2620	781,81	13,837	14,432	3030	931,58	16,488	17,196	3440	1087,4	19,246	20,072
2220	641,53	11,354	11,842	2630	785,39	13,901	14,498	3040	935,31	16,554	17,265	3450	1091,3	19,314	20,144
2230	644,97	11,415	11,906	2640	788,98	13,964	14,564	3050	939,04	16,620	17,334	3460	1095,2	19,383	20,215
2240	648,41	11,476	11,969	2650	792,57	14,028	14,630	3060	942,77	16,686	17,403	3470	1099,0	19,452	20,287
2250	651,85	11,537	12,033	2660	796,16	14,091	14,696	3070	946,51	16,752	17,472	3480	1102,9	19,521	20,359
2260	655,30	11,598	12,096	2670	799,75	14,155	14,763	3080	950,26	16,819	17,541	3490	1106,8	19,589	20,431
2270	658,75	11,659	12,160	2680	803,35	14,219	14,829	3090	954,00	16,885	17,610	3500	1110,7	19,658	20,503
2280	662,21	11,720	12,224	2690	806,95	14,282	14,896	3100	957,75	16,951	17,679	3510	1114,6	19,727	20,574
2290	665,66	11,782	12,288	2700	810,56	14,346	14,962	3110	961,51	17,018	17,748	3520	1118,5	19,796	20,646
2300	669,13	11,843	12,351	2710	814,17	14,410	15,029	3120	965,26	17,084	17,818	3530	1122,4	19,865	20,719
2310	672,59	11,904	12,415	2720	817,78	14,474	15,096	3130	969,02	17,151	17,887	3540	1126,3	19,935	20,791
2320	676,06	11,966	12,479	2730	821,40	14,538	15,162	3140	972,79	17,217	17,957	3550	1130,2	20,004	20,863
2330	679,53	12,027	12,544	2740	825,02	14,602	15,229	3150	976,56	17,284	18,026	3560	1134,1	20,073	20,935
2340	683,01	12,089	12,608	2750	828,64	14,666	15,296	3160	980,33	17,351	18,096	3570	1138,1	20,143	21,008
2350	686,49	12,150	12,672	2760	832,27	14,730	15,363	3170	984,10	17,418	18,166	3580	1142,0	20,212	21,080
2360	689,97	12,212	12,736	2770	835,90	14,795	15,430	3180	987,88	17,485	18,235	3590	1145,9	20,281	21,152
2370	693,46	12,274	12,801	2780	839,54	14,859	15,497	3190	991,66	17,551	18,305	3600	1149,8	20,351	21,225

Lâmpada de Stefan-Boltzmann 1008523

Instruções de operação

02/24 NF/ALF/UD



1. Indicações de segurança

A lâmpada de Stefan-Boltzmann corresponde às determinações de segurança para dispositivos elétricos de medição, de comando, de regulação e de laboratório segundo DIN EN 61010 parte 1. Ela foi projetada para a operação em ambientes secos, que são apropriados para os meios de operação elétricos.

Na utilização segundo foi determinado, o uso seguro do equipamento é garantido. A segurança, não obstante, não é garantida, quando os aparelhos são operados de forma imprópria ou são manuseados sem os devidos cuidados.

Atenção:

A lâmpada fica muito quente durante a operação. Existe o perigo de queimaduras no contato! Adicionalmente podem-se marcar resíduos gordurosos por queimadura.

- Não segurar a lâmpada com os dedos.
- Ao finalizar a experiência deixar esfriar a lâmpada.

Dica:

No caso de tensões de conexão superiores a 13 V o fio incandescente será destruído.

- Jamais ligar uma tensão superior a 13 V nas duas tomadas de 4 mm.

2. Descrição

A lâmpada de Stefan-Boltzmann é uma fonte de alta temperatura com um fio incandescente de Wolfram. Ela serve para a produção de radiação de calor e para a avaliação da sua dependência de temperatura, respectivamente, para a confirmação da lei de Stefan-Boltzmann na forma de

$$P = \varepsilon \cdot \sigma \cdot A \cdot T^4.$$

Nisto P é a potência radiada, T é a temperatura absoluta do fio incandescente, A a sua superfície, σ é a constante de Stefan-Boltzmann e ε é uma constante sem dimensão entre 0 e 1. Com isto a temperatura da lâmpada é calculada da resistência da espiral de aquecimento.

O fio incandescente representa numa aproximação muito boa uma fonte de radiação pontual e com isto é adequado para a avaliação da lei da raiz quadrada recíproca da distância.

3. Fornecimento

1 Lâmpada de Stefan-Boltzmann
1 Vara de apoio, comprimento de 130 mm

4. Dados técnicos

Tensão nominal:	12 V DC
Corrente nominal:	1,75 A
Potência nominal:	21 W
Valores de operação máx.:	13 V DC / 2 A
Temperatura máxima do fio incandescente:	3600 K
Distância do fio incandescente para a vara de apoio:	25 mm

5. Exemplo de medição

Adicionalmente necessário:

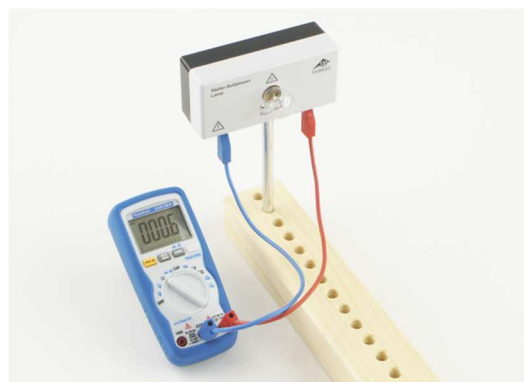
1 Coluna térmica segundo Moll 1000824
1 Fonte de alimentação DC 20 V, 5 A (@230V) 1003312

ou

1 Fonte de alimentação DC 20 V, 5 A (@115V) 1003311

1 Multímetro digital P3340 1002785
2 Multímetros digitais P1035 1002781
2 Bases em tonel 1000 g 1002834
1 Conjunto de 15 cabos de segurança para experiências, 75 cm 1002843

5.1 Medição da resistência do fio incandescente em temperatura de ambiente



- Inserir cada uma das ligações de medição nas tomadas de COM- e de V Ω mA do multímetro digital P3340 (1002785) e curto-circuitar.
- Selecionar a escala de Ω , aguardar pela indicação de zero, e seguidamente apertar brevemente a tecla de REL.
- Abrir o curto-circuito da conexão de medição e inserir as ligações nas duas tomadas da lâmpada de Stefan-Boltzmann.
- Ler o valor da resistência R_{ref} e anotar (Tab. 1).
- Retirar as ligações de medição.
- Com o sensor térmico do multímetro medir na proximidade da lâmpada a temperatura do ambiente T_{ref} em Kelvin e anotar (Tab. 1).

Tab. 1: Valor da resistência do fio incandescente medido em temperatura de ambiente

R_{ref}	0,541 Ω
T_{ref}	297 K

5.2 Medição da intensidade da radiação em dependência da temperatura verificada do fio incandescente



- Conectar a coluna térmica ao multímetro digital P3340 (1002785).
- Montar a lâmpada de Stefan-Boltzmann diante da coluna térmica e interconectá-la com a fonte de alimentação DC e os dois multímetros digitais P1035 (1002781).
- Ajustar a tensão U aumentando a cada vez em 1 V até máx. 12 V e medir a tensão U da lâmpada e a corrente I da lâmpada e, com a coluna térmica, a intensidade radiada Φ (5.3, Tab. 2).

5.3 Avaliação

- Calcular $R = U/I$ (Tab. 2).
- Com os valores verificados T_{ref} , R_{ref} , R e os coeficientes de resistência e temperatura $\alpha = 4,4 \cdot 10^{-3} \text{ K}^{-1}$ para Wolfram, a temperatura do fio incandescente pode ser calculada segundo a fórmula

$$T = \left(\frac{R - R_{\text{ref}}}{\alpha \cdot R_{\text{ref}}} \right) + T_{\text{ref}}$$

Uma possibilidade alternativa para a determinação da temperatura T do fio incandescente é, calcular o quociente R / R_{ref} e deste, com a ajuda da Fig. 2, respectivamente, da Tab. 3 no apêndice, verificar a temperatura.

Indicação: Na Tab. 3 é indicado o quociente R / R_{ref} tanto para $T_{\text{ref}} = 300 \text{ K}$ como também para $T_{\text{ref}} = 290 \text{ K}$. Para uma análise mais precisa pode ser interpolado entre esses valores, para tomar em consideração a temperatura de ambiente real.

- Representar Φ em dependência de T^4 (Fig. 3).

Tab. 2: Valores para a resistência R e a temperatura T do fio incandescente calculados a partir dos valores medidos para a tensão U da lâmpada e a corrente I da lâmpada, bem como a intensidade radiada Φ medida com a coluna térmica.

U / V	I / A	R / Ω	T / K	Φ / V
0,00369	0,006	0,615	328	0
1,0502	0,554	1,896	854	0,0001
2,033	0,706	2,879	1259	0,0004
3,012	0,837	3,599	1554	0,0011
4,003	0,958	4,178	1792	0,0019
5,012	1,071	4,679	1998	0,0029
6,017	1,174	5,125	2181	0,0042
7,074	1,276	5,5434	2353	0,0058
8,028	1,362	5,894	2497	0,0072
9,011	1,446	6,232	2636	0,0088
10,088	1,534	6,576	2777	0,0106
11,02	1,607	6,8575	2893	0,0125
11,685	1,68	6,955	2933	0,0145

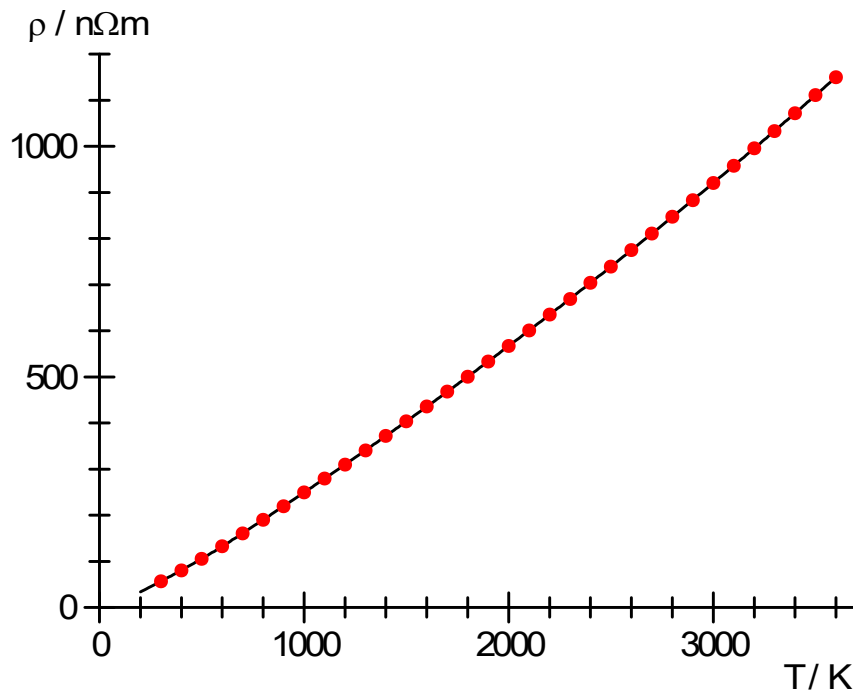


Fig. 1: Resistência específica ρ de Wolfram em dependência da temperatura absoluta T (ver Tab. 3). A curva foi adaptada aos valores de medição de Zerda, T.W., Texas Christian University. 2001

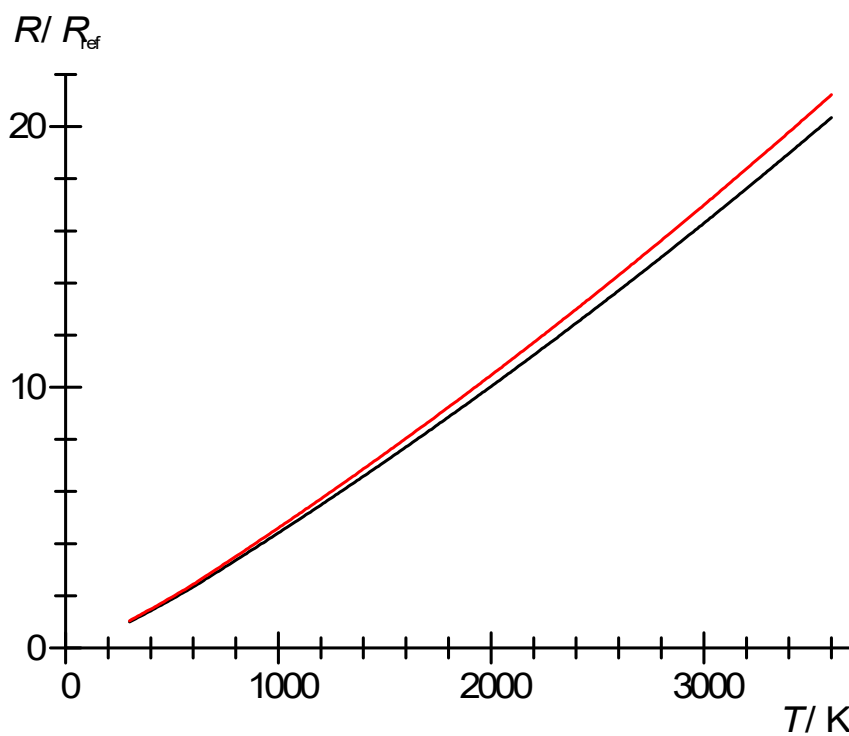


Fig. 2: As relações de resistências $R(T) / R_{300 \text{ K}}$ (preto), respectivamente, $R(T) / R_{290 \text{ K}}$ (vermelho) calculados a partir dos valores mostrados na Fig. 1 (ver Tab. 3)

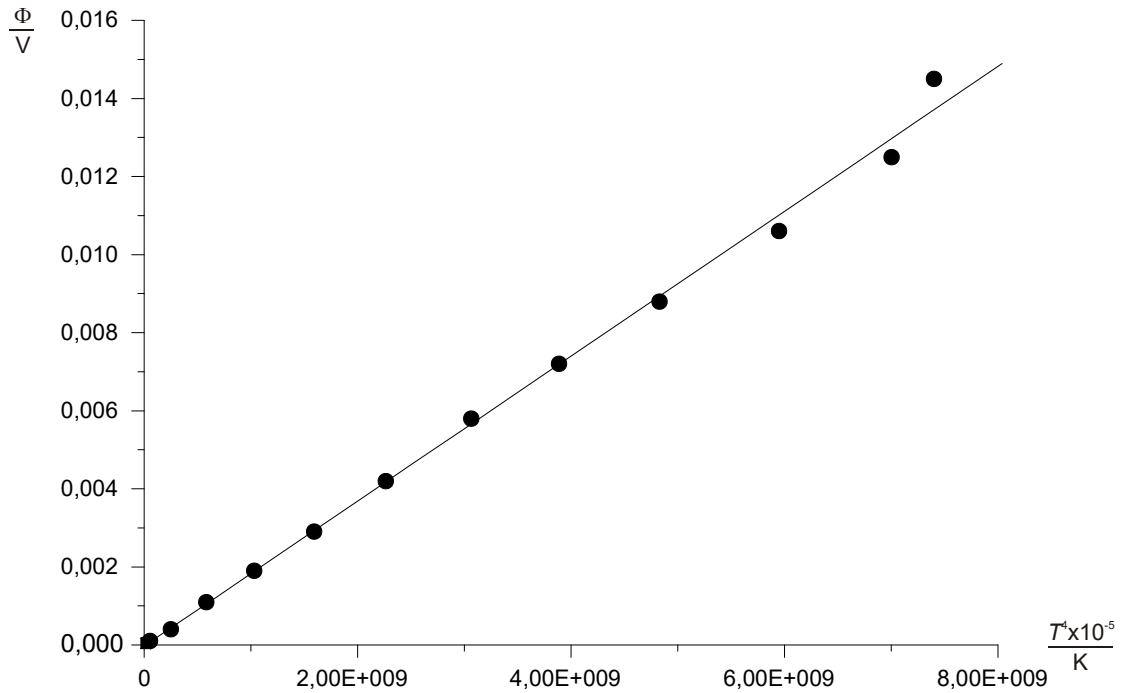


Fig. 3: Intensidade de radiação Φ em dependência da temperatura T

6 Troca da lâmpada

Para a troca de lâmpada são necessárias adicionalmente as seguintes ferramentas:

1 Lâmpada de 12 V / 21 W, base BA15S

1 Chave de fenda

1 Papel de lixa

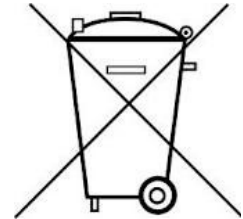
1 Ferro de solda

Estanho para solda

- Desparafusar a cobertura do verso da armação.
- Dessoldar a lâmpada.
- Lixar e estancar os lugares onde vai ser soldado o fio da nova lâmpada.
- Inserir a lâmpada e soldar-a.
- Testar a lâmpada com 12 V.
- Aparafusar de novo a armação.

7. Descarte

- A embalagem deve ser descartada nos postos de reciclagem locais.
- Em caso que o próprio aparelho deve ser sucateado, ele não pertence ao lixo caseiro normal. Devem ser cumpridas as regulamentações locais para o descarte de sucata eletrônica.



8. Apêndice

Tab. 3: Resistência específica ρ de Wolfram em dependência da temperatura absoluta T e as relações de resistências daí calculadas $R(T) / R_{300 \text{ K}}$, respectivamente, $R(T) / R_{290 \text{ K}}$. (ver Fig. 1 e Fig. 2)

$\frac{T}{\text{K}}$	ρ n Ωm	$\frac{R(T)}{R_{300\text{K}}}$	$\frac{R(T)}{R_{290\text{K}}}$	$\frac{T}{\text{K}}$	ρ n Ωm	$\frac{R(T)}{R_{300\text{K}}}$	$\frac{R(T)}{R_{290\text{K}}}$	$\frac{T}{\text{K}}$	ρ n Ωm	$\frac{R(T)}{R_{300\text{K}}}$	$\frac{R(T)}{R_{290\text{K}}}$	$\frac{T}{\text{K}}$	ρ n Ωm	$\frac{R(T)}{R_{300\text{K}}}$	$\frac{R(T)}{R_{290\text{K}}}$
290	54,17	1,000		710	163,86	2,900	3,025	1130	288,49	5,106	5,325	1550	419,46	7,424	7,743
300	56,50	1,000	1,043	720	166,76	2,951	3,078	1140	291,53	5,160	5,381	1560	422,65	7,481	7,802
310	58,84	1,041	1,086	730	169,65	3,003	3,132	1150	294,58	5,214	5,438	1570	425,85	7,537	7,861
320	61,19	1,083	1,130	740	172,55	3,054	3,185	1160	297,63	5,268	5,494	1580	429,06	7,594	7,920

330	63,56	1,125	1,173	750	175,46	3,105	3,239	1170	300,69	5,322	5,550	1590	432,26	7,651	7,979
340	65,93	1,167	1,217	760	178,37	3,157	3,292	1180	303,75	5,376	5,607	1600	435,47	7,707	8,038
350	68,33	1,209	1,261	770	181,28	3,208	3,346	1190	306,81	5,430	5,663	1610	438,69	7,764	8,098
360	70,73	1,252	1,306	780	184,19	3,260	3,400	1200	309,87	5,484	5,720	1620	441,90	7,821	8,157
370	73,14	1,295	1,350	790	187,11	3,312	3,454	1210	312,94	5,539	5,777	1630	445,13	7,878	8,217
380	75,57	1,338	1,395	800	190,03	3,363	3,508	1220	316,02	5,593	5,833	1640	448,35	7,935	8,276
390	78,02	1,381	1,440	810	192,96	3,415	3,562	1230	319,09	5,648	5,890	1650	451,58	7,992	8,336
400	80,47	1,424	1,485	820	195,89	3,467	3,616	1240	322,18	5,702	5,947	1660	454,81	8,050	8,395
410	82,94	1,468	1,531	830	198,82	3,519	3,670	1250	325,26	5,757	6,004	1670	458,05	8,107	8,455
420	85,42	1,512	1,577	840	201,76	3,571	3,724	1260	328,35	5,811	6,061	1680	461,28	8,164	8,515
430	87,91	1,556	1,623	850	204,70	3,623	3,779	1270	331,44	5,866	6,118	1690	464,53	8,222	8,575
440	90,42	1,600	1,669	860	207,64	3,675	3,833	1280	334,53	5,921	6,175	1700	467,77	8,279	8,635
450	92,94	1,645	1,716	870	210,59	3,727	3,887	1290	337,63	5,976	6,232	1710	471,02	8,337	8,695
460	95,47	1,690	1,762	880	213,54	3,779	3,942	1300	340,73	6,031	6,290	1720	474,28	8,394	8,755
470	98,02	1,735	1,809	890	216,50	3,832	3,996	1310	343,84	6,086	6,347	1730	477,53	8,452	8,815
480	100,57	1,780	1,857	900	219,45	3,884	4,051	1320	346,95	6,141	6,404	1740	480,79	8,510	8,875
490	103,15	1,826	1,904	910	222,42	3,937	4,106	1330	350,06	6,196	6,462	1750	484,06	8,567	8,935
500	105,73	1,871	1,952	920	225,38	3,989	4,160	1340	353,18	6,251	6,519	1760	487,33	8,625	8,996
510	108,33	1,917	2,000	930	228,35	4,042	4,215	1350	356,30	6,306	6,577	1770	490,60	8,683	9,056
520	110,93	1,963	2,048	940	231,32	4,094	4,270	1360	359,42	6,361	6,635	1780	493,87	8,741	9,116
530	113,56	2,010	2,096	950	234,30	4,147	4,325	1370	362,55	6,417	6,692	1790	497,15	8,799	9,177
540	116,19	2,056	2,145	960	237,28	4,200	4,380	1380	365,68	6,472	6,750	1800	500,43	8,857	9,238
550	118,84	2,103	2,194	970	240,26	4,252	4,435	1390	368,82	6,528	6,808	1810	503,72	8,915	9,298
560	121,50	2,150	2,243	980	243,25	4,305	4,490	1400	371,95	6,583	6,866	1820	507,01	8,974	9,359
570	124,17	2,198	2,292	990	246,24	4,358	4,545	1410	375,10	6,639	6,924	1830	510,30	9,032	9,420
580	126,86	2,245	2,342	1000	249,23	4,411	4,601	1420	378,24	6,695	6,982	1840	513,60	9,090	9,481
590	129,56	2,293	2,392	1010	252,23	4,464	4,656	1430	381,39	6,750	7,040	1850	516,90	9,149	9,541
600	132,27	2,341	2,442	1020	255,23	4,517	4,711	1440	384,54	6,806	7,098	1860	520,20	9,207	9,602
610	135,13	2,392	2,494	1030	258,24	4,571	4,767	1450	387,70	6,862	7,157	1870	523,51	9,266	9,663
620	137,98	2,442	2,547	1040	261,25	4,624	4,822	1460	390,86	6,918	7,215	1880	526,82	9,324	9,725
630	140,85	2,493	2,600	1050	264,26	4,677	4,878	1470	394,02	6,974	7,273	1890	530,13	9,383	9,786
640	143,71	2,544	2,653	1060	267,28	4,731	4,934	1480	397,19	7,030	7,332	1900	533,45	9,442	9,847
650	146,58	2,594	2,706	1070	270,29	4,784	4,989	1490	400,36	7,086	7,390	1910	536,77	9,500	9,908
660	149,45	2,645	2,759	1080	273,32	4,837	5,045	1500	403,53	7,142	7,449	1920	540,10	9,559	9,970
670	152,33	2,696	2,812	1090	276,34	4,891	5,101	1510	406,71	7,198	7,508	1930	543,43	9,618	10,031
680	155,20	2,747	2,865	1100	279,37	4,945	5,157	1520	409,89	7,255	7,566	1940	546,76	9,677	10,093
690	158,09	2,798	2,918	1110	282,41	4,998	5,213	1530	413,08	7,311	7,625	1950	550,10	9,736	10,154
700	160,97	2,849	2,971	1120	285,45	5,052	5,269	1540	416,27	7,368	7,684	1960	553,44	9,795	10,216

$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$	$\frac{T}{K}$	$\frac{\rho}{n\Omega m}$	$\frac{R(T)}{R_{300K}}$	$\frac{R(T)}{R_{290K}}$
1970	556,78	9,854	10,278	2380	696,95	12,335	12,865	2790	843,18	14,923	15,564	3200	995,45	17,618	18,375
1980	560,13	9,914	10,339	2390	700,45	12,397	12,930	2800	846,82	14,988	15,631	3210	999,24	17,686	18,445
1990	563,48	9,973	10,401	2400	703,95	12,459	12,994	2810	850,46	15,052	15,699	3220	1003,0	17,753	18,515
2000	566,83	10,032	10,463	2410	707,45	12,521	13,059	2820	854,11	15,117	15,766	3230	1006,8	17,820	18,585
2010	570,19	10,092	10,525	2420	710,95	12,583	13,124	2830	857,77	15,182	15,834	3240	1010,6	17,887	18,655
2020	573,55	10,151	10,587	2430	714,46	12,645	13,188	2840	861,42	15,246	15,901	3250	1014,4	17,954	18,725
2030	576,91	10,211	10,649	2440	717,97	12,707	13,253	2850	865,08	15,311	15,969	3260	1018,2	18,022	18,796
2040	580,28	10,270	10,711	2450	721,49	12,770	13,318	2860	868,75	15,376	16,036	3270	1022,1	18,089	18,866
2050	583,65	10,330	10,774	2460	725,01	12,832	13,383	2870	872,41	15,441	16,104	3280	1025,9	18,157	18,937
2060	587,03	10,390	10,836	2470	728,53	12,894	13,448	2880	876,08	15,506	16,172	3290	1029,7	18,224	19,007
2070	590,41	10,450	10,898	2480	732,06	12,957	13,513	2890	879,76	15,571	16,240	3300	1033,5	18,292	19,078
2080	593,79	10,510	10,961	2490	735,59	13,019	13,578	2900	883,44	15,636	16,307	3310	1037,3	18,360	19,148
2090	597,18	10,569	11,023	2500	739,12	13,082	13,644	2910	887,12	15,701	16,375	3320	1041,2	18,428	19,219
2100	600,57	10,629	11,086	2510	742,66	13,144	13,709	2920	890,80	15,766	16,443	3330	1045,0	18,495	19,290
2110	603,96	10,690	11,149	2520	746,20	13,207	13,774	2930	894,49	15,832	16,511	3340	1048,8	18,563	19,360
2120	607,36	10,750	11,211	2530	749,75	13,270	13,840	2940	898,18	15,897	16,580	3350	1052,7	18,631	19,431
2130	610,76	10,810	11,274	2540	753,30	13,333	13,905	2950	901,88	15,962	16,648	3360	1056,5	18,699	19,502
2140	614,17	10,870	11,337	2550	756,85	13,395	13,971	2960	905,58	16,028	16,716	3370	1060,4	18,767	19,573
2150	617,57	10,930	11,400	2560	760,40	13,458	14,036	2970	909,28	16,093	16,785	3380	1064,2	18,836	19,644
2160	620,99	10,991	11,463	2570	763,96	13,521	14,102	2980	912,99	16,159	16,853	3390	1068,1	18,904	19,716
2170	624,40	11,051	11,526	2580	767,53	13,584	14,168	2990	916,70	16,225	16,921	3400	1071,9	18,972	19,787
2180	627,82	11,112	11,589	2590	771,09	13,648	14,234	3000	920,41	16,290	16,990	3410	1075,8	19,040	19,858
2190	631,24	11,172	11,652	2600	774,66	13,711	14,300	3010	924,13	16,356	17,059	3420	1079,7	19,109	19,929
2200	634,67	11,233	11,715	2610	778,24	13,774	14,366	3020	927,85	16,422	17,127	3430	1083,5	19,177	20,001
2210	638,10	11,294	11,779	2620	781,81	13,837	14,432	3030	931,58	16,488	17,196	3440	1087,4	19,246	20,072
2220	641,53	11,354	11,842	2630	785,39	13,901	14,498	3040	935,31	16,554	17,265	3450	1091,3	19,314	20,144
2230	644,97	11,415	11,906	2640	788,98	13,964	14,564	3050	939,04	16,620	17,334	3460	1095,2	19,383	20,215
2240	648,41	11,476	11,969	2650	792,57	14,028	14,630	3060	942,77	16,686	17,403	3470	1099,0	19,452	20,287
2250	651,85	11,537	12,033	2660	796,16	14,091	14,696	3070	946,51	16,752	17,472	3480	1102,9	19,521	20,359
2260	655,30	11,598	12,096	2670	799,75	14,155	14,763	3080	950,26	16,819	17,541	3490	1106,8	19,589	20,431
2270	658,75	11,659	12,160	2680	803,35	14,219	14,829	3090	954,00	16,885	17,610	3500	1110,7	19,658	20,503
2280	662,21	11,720	12,224	2690	806,95	14,282	14,896	3100	957,75	16,951	17,679	3510	1114,6	19,727	20,574
2290	665,66	11,782	12,288	2700	810,56	14,346	14,962	3110	961,51	17,018	17,748	3520	1118,5	19,796	20,646
2300	669,13	11,843	12,351	2710	814,17	14,410	15,029	3120	965,26	17,084	17,818	3530	1122,4	19,865	20,719
2310	672,59	11,904	12,415	2720	817,78	14,474	15,096	3130	969,02	17,151	17,887	3540	1126,3	19,935	20,791
2320	676,06	11,966	12,479	2730	821,40	14,538	15,162	3140	972,79	17,217	17,957	3550	1130,2	20,004	20,863
2330	679,53	12,027	12,544	2740	825,02	14,602	15,229	3150	976,56	17,284	18,026	3560	1134,1	20,073	20,935
2340	683,01	12,089	12,608	2750	828,64	14,666	15,296	3160	980,33	17,351	18,096	3570	1138,1	20,143	21,008
2350	686,49	12,150	12,672	2760	832,27	14,730	15,363	3170	984,10	17,418	18,166	3580	1142,0	20,212	21,080
2360	689,97	12,212	12,736	2770	835,90	14,795	15,430	3180	987,88	17,485	18,235	3590	1145,9	20,281	21,152
2370	693,46	12,274	12,801	2780	839,54	14,859	15,497	3190	991,66	17,551	18,305	3600	1149,8	20,351	21,225