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Energy Division

PERFORMANCE TESTING OF A COMMERCIALY
PRODUCED CRYOGENIC REFRIGERATOR

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ABSTRACT

A commercially available cryogenic refrigeration unit, model M-20, (3-phase, 60-Hz, 230-V) manufactured by Cryodynamics, Inc., was subjected to laboratory testing to measure some of its performance characteristics. Comparisons were made with those performance characteristics given in manufacturer literature for the M-20 unit (3-phase, 400-Hz, 208-V). At 77 K, the measured cooling capacity of the 60-Hz/230-V unit was very nearly the same (<2% difference) as the specified capacity (110 W) of the 400-Hz/208-V unit. At temperature levels higher than 77 K, measured cooling capacities exceeded the manufacturer product data sheet values. Coefficients of performance (COP) based on the experimental measurements ranged from about 0.37 at 250 K to 0.03 at 70 K. Comparison of measured to ideal (Carnot cycle) COPs yielded values ranging from about 8 to 18%, with a broad maximum occurring between approximately 100 and 150 K. Finally, the measured cool-down time from room temperature to 77 K was about 10 minutes compared with a specification sheet value of 7.4 minutes. This difference may be attributed to lower thermal mass (without heater block) and higher operating frequency conditions associated with the specification.

INTRODUCTION

For several years Cryodynamics, Inc., has produced a line of compact closed-cycle cryogenic refrigeration units that are employed in numerous military, aerospace, and industrial applications. The units use helium as the working fluid in a modified Stirling cycle system. Refrigeration units have been produced that provide cooling at a temperature level as low as 25 K. A more recent application employs a unit that provides 25,000 Btu/h of cooling at 0°F for trailer-truck payload refrigeration. One of the very attractive features of such refrigeration units is their use of helium as a working medium rather than chlorofluorocarbon refrigerants, since any leakage of helium into the atmosphere is without the deleterious environmental consequences of chlorofluorocarbon refrigerant fluids.

Because of the potential for the worldwide use of non-polluting refrigeration systems, tests were conducted at the Mechanical and Aerospace Engineering Department of The University of Tennessee on a refrigeration unit (Cryodynamics, Inc., Model M-20) to establish its performance capabilities. The performance tests conducted are described herein, with quantitative results tabulated and presented in graphical form.

EXPERIMENTAL SETUP

The Cryodynamics M-20 refrigeration unit was installed on a portable bench top. The M-20 unit, with auxiliary apparatus and instrumentation, is illustrated in Fig. 1. Shown in the figure are (1) the M-20 unit, (2) a vacuum pump, (3) a wattmeter (for measuring input power), (4) a variable transformer (for controlling the heating load to the cooling head of the cryocooler), (5) an ohmmeter (for measuring the temperature of the cooling head via a calibrated resistance thermometer), and (6) a fan (for heat rejection to ambient air).

Fig. 1. Photograph of experimental apparatus.

Relative to the design details of the M-20 unit, a description consisting of the product data sheet supplied by Cryodynamics is presented in Appendix I. Engineering details of the Stirling cycle piston-regenerator system itself are considered proprietary. However, a schematic representation of the internals of a compact Stirling cycle unit is shown in Appendix I.

For the tests reported here, the cooling head of the M-20 unit was equipped with a top-mounted heater block and a surrounding vacuum jacket. As shown in Fig. 2, four electric cartridge heaters were installed in the upper section of the copper heater block to provide the heat load required for performance measurements. To reduce thermal contact resistance, Dow-Corning 340 grease was applied to the mating surfaces. A platinum resistance thermometer was fastened to the lower section of the block by means of a small bolted metallic tab. The heater block assembly was bolted to the upper cooling head surface. The vacuum jacket provided an airtight enclosure around the cooling head, which, when evacuated by the vacuum pump arrangement illustrated in Fig. 1, minimized convection heat leaks from the surroundings to the cooling head.

The M-20 unit operated on 3-phase, 60-Hz, 230-V AC power measured with a wattmeter having a least count of 0.01 kW. Power input to the cartridge heaters was controlled by a variable transformer and measured by means of a voltmeter (least count of 0.1 V) and an ammeter (least count of 0.01 A). The resistance of the thermometer element was measured with a digital multimeter (least count of 0.01 Ω). The element itself was calibrated such that a precision of about 0.02 K was possible. (The complete temperature-resistance relationship for the element is presented in Appendix II.) Ambient air temperature was monitored with a mercury-in-glass thermometer located near the air inlet to the refrigeration unit.

A detailed listing and description of test equipment is presented in Appendix II.

Fig. 2. Photograph of cartridge heaters and resistance thermometer element affixed to M-20 cooling head shortly after removal of vacuum jacket.

PROCEDURE

Tests were conducted on two consecutive days. Each day, tests were initiated after the vacuum jacket had been pumped down to 15 μ m Hg. After the M-20 unit had been activated, temperature measurements of the cooling head were made 1 minute apart to establish the cool-down time required to reach the desired initial operating temperature level. Measurements were made of the cooling head temperature, power to the cartridge heaters (volts and amps), power to the M-20 unit (which includes power to the cooling fan), ambient air temperature, and vacuum-jacket pressure.

On the first day of the testing, the initial operating temperature level was approximately 77 K. Thereafter, the operating temperature was consistently increased up to a maximum of 250 K and returned to the 77 K level. Selected operating temperature levels were attained by adjusting the energy input level to the cartridge heaters (i.e., by applying increasingly larger heating loads to the cooling head and obtaining higher operating temperature levels).

On the second day, cool down to 70 K was first performed. Thereafter, the operating temperature levels were varied in a "ratchet-like" fashion, rather than in a continuously increasing manner. That is, temperature levels in sequence were 70, 77, 120, 100, 175, and 150 K.

Prior to the tests, measurements were made of power input to the cooling fan, which removes both the energy input to the M-20 unit and ultimately the load under which the cryocooler operates (removes from the cartridge heaters) at a given temperature level. The power level to the fan was found to be about 200 W. Thus, the measured total power to the M-20 system includes about 200 W of fan power.

RESULTS

The measured results of the two-day testing program are tabulated in Table 1. Additionally, from the measured values of the cooling load and input power to the M-20 (subtracting 200 W that was used to drive the heat rejection fan), the coefficient of performance (COP) has been calculated at numerous operating temperature levels.

The ideal COP (Carnot refrigerator COP) has been calculated based on the temperature extremes of cooling head temperature and ambient air temperature (Table 2). Also in Table 2, the actual COP for the M-20 is compared with the Carnot COP in terms of the ratio, COP/COP_{ideal} .

In Fig. 3, the measured cooling capacities for both testing days (as reflected by the maintenance of a steady cooling head temperature when subjected to a steady heating input) are shown superimposed. Although the cooling capacity data were gathered in two different sequences (steadily increasing operating temperature levels vs "ratcheted" levels), good agreement appears to exist between the two sets of data. This agreement increased confidence in the experimental measurements made, in the techniques employed, and in the operational stability of the M-20 unit.

Figure 4 repeats a portion of the cooling capacity data shown in Fig. 3 (i.e., data only from the first day) and also presents the COP values calculated from the measured cooling capacity and power input data. It is of interest to observe that above 77 K the measured cooling capacities are somewhat higher than the manufacturer product data sheet values for the 400-Hz/208 V unit (dashed line). Those values are available only over a limited temperature range and have been obtained from the literature (Appendix I).

Table 1. Performance data and calculated COP values for M-20 unit tested

Time	Cooling head temperature		Heater power (cooling load)		Power to M-20 & fan (kW)		Ambient air temperature (°F)	Vacuum (μm-Hg)	COP
	(Ω)	(K)	(V)	(A)	(W)	(W)			
(first day)									
(on) 1:08	110.70	300.0	0	0	0	0	82	15	
1:09:20	99.00	270.0	0	0	0	0			
1:10	91.44	252	0	0	0	0			
1:11	80.33	224	0	0	0	0		15	
1:12	69.60	198	0	0	0	0			
1:13	60.14	175	0	0	0	0			
1:14	51.13	153	0	0	0	0			
1:15	42.35	132	0	0	0	0			
1:16	34.33	113	0	0	0	0			
1:17	26.87	96	0	0	0	0			
1:18	20.48	81	0	0	0	0			
1:18:20	18.74	77	0	0	0	0			
1:24	18.59	76.65	48.7	2.21	108	2.34	82	15	
1:26	18.65	76.85	48.7	2.21	108	2.40	82	13	0.0491
1:32	21.95	83.86	57.5	2.62	151	2.38	83	13	
1:36	27.71	97.64	64.2	2.92	187	2.24	83	13	
1:39	28.89	100.44	62.2	2.83	176	2.23	83	13	

Table 1 (continued)

Time	Cooling head temperature		Heater power (cooling load)		Power to M-20 & fan (kW)	Ambient air temperature (°F)	Vacuum (μ m-Hg)	COP
	(Ω)	(K)	(V)	(A)	(W)			
1:41	28.85	100.30	61.8	2.81	174	83	13	0.0857
1:47	35.94	116.84	71.0	3.22	229	83	13	
1:50	37.19	119.77	69.5	3.15	220	83	13	
1:54	37.36	120.17	68.3	3.10	212	83	13	0.115
2:08	49.00	147.76	78.7	3.57	281	84	13	
2:12	49.92	149.98	77.5	3.51	272	85	13	0.173
2:27	60.26	174.86	83.0	3.76	312	85	13	0.223
2:38	69.40	197.12	90.2	4.07	367	85	13	
2:44	70.52	199.85	87.8	3.96	348	85	13	0.278
3:00	80.75	225.02	91.5	4.12	377	85	13	0.319
3:15	91.00	250.47	94.8	4.26	404	85	20	
3:18	90.81	250.00	95.1	4.27	406	85	20	0.369
3:29:20	18.74	77.0	0	0	0	85	12	
3:34	15.79	70.14	41.1	1.87	76.9	85	11	0.0314
(second day)								
10:41	112.00	303.6	0	0	0	82	15	
10:42	97.71	267.3	0	0	0			
10:43	86.31	238.8	0	0	0			

Table 1 (continued)

Time	Cooling head temperature		Heater power (cooling load)		Power to M-20 & fan (kW)	Ambient air temperature (°F)	Vacuum ($\mu\text{m-Hg}$)	COP
	(Ω)	(K)	(V)	(A)				
10:44	75.04	211.0	0	0	0			
10:45	63	181.5	0	0	0			
10:46	55	162.2	0	0	0			
10:47	46	140.6	0	0	0			
10:48	38.36	122.5	0	0	0			
10:49	30.81	104.9	0	0	0			
10:50	24.00	89.1	0	0	0			
10:51	18.74	77.0	0	0	0			
10:55		~70	41.2	1.87	77.0	84	13	
10:58	15.74	70.0	43.2	1.97	85.1	94	13	0.0358
11:08	18.70	76.9	46.2	2.10	97.0	86	13	0.0399
11:29	37.30	120.0	67.4	3.06	206	86	13	0.111
11:50	28.78	100.1	58.9	2.68	158	86	15	0.0755
12:00	60.32	175.0	84.1	3.78	318	87	15	0.222
12:10	49.87	143.9	77.6	3.52	273	87	15	0.174

Table 2. Data tabulation for COP computation and comparison with Carnot cycle COP

Time	Temperature (K)	Cooling load (W)	Power to M-20 (W)	COP	COP _{ideal}	COP/COP _{ideal}
1:26 (first day)	76.9	108	2200	0.0491	0.345	0.142
1:41	100.3	174	2030	0.0857	0.502	0.171
1:54	119.1	212	1840	0.115	0.658	0.175
2:12	150.0	272	1570	0.173	1.00	0.173
2:27	174.9	312	1400	0.223	1.40	0.159
2:44	199.9	348	1250	0.278	2.00	0.139
3:00	225.0	377	1180	0.319	3.00	0.106
3:18	250.0	406	1100	0.369	5.00	0.0738
3:34	70.1	76.9	2450	0.0314	0.305	0.102
10:58 (second day)	70.0	85.1	2380	0.0358	0.300	0.119
11:08	76.9	97.0	2430	0.0399	0.339	0.118
11:29	120.0	206	1860	0.111	0.654	0.170
11:50	100.1	158	2090	0.0755	0.492	0.153
12:00	175.0	318	1430	0.222	1.36	0.163
12:10	149.9	273	1570	0.174	0.975	0.178

Fig. 3. Performance of M-20 unit measured on two consecutive testing days.

Fig. 4. Performance characteristics of M-20 unit in terms of cooling capacity and COP (first day data only).

Figure 5 compares the actual COP (calculated from measured values) with the COP of an ideal Carnot refrigeration system. As ideal conditions are approached, the ratio of the values approaches unity. The maximum value obtained here is nearly 0.18. A broad maximum appears evident over the temperature range from about 100 to 150 K. This maximum appears to reflect an operation that is optimal over that range, though the unit was apparently intended to provide cooling at a 77-K level. The display of data in this manner may be helpful in identifying the potential for design improvements required in different operating temperature ranges. Ultimately, such improvements would result in such refrigerating units approaching the Carnot cycle COP more closely.¹

In Fig. 6, the cool-down time to 77 K on both test days is seen to be about 10 minutes as compared to the 7.4-minute value appearing in the specifications of Appendix I. According to the manufacturer, two primary factors account for this difference. First, during the manufacturer cool-down tests, no heater block was installed on the cold head. The substantial additional thermal mass of the copper block and cartridge heaters installed for the tests reported here would be expected to increase the apparent cool-down time. Second, the manufacturer tests were conducted with a 400-Hz/208-V unit rather than the 60-Hz/230-V unit used here. The higher frequency unit might be expected to provide more rapid cool downs.

SUMMARY

From these tests of the performance characteristics of the Cryodynamics M-20 refrigerator, the following observations may be made:

¹The manufacturer claims the ability to change the width and height of the performance curve as well as the position of the curve peak by suitable design parameter modifications.

Fig. 5. Comparison of actual performance of M-20 unit with that of Carnot cycle system.

Fig. 6. Cool-down characteristics of the M-20 unit.

1. Measured cooling capacities of the unit appear to exceed the manufacturer product data sheet values at temperatures above 77 K.
2. At 77 K the measured cooling capacity is less than 2% lower than the manufacturer's quoted value. This result indicates reasonable agreement, considering experimental uncertainties -- especially those associated with different power frequency/voltage operating conditions for the two units compared.
3. The reproducibility of the measured cooling capacity results on two separate days of testing and in different loading sequences appears to lend confidence to the measurement system itself and to indicate stable operational characteristics in the M-20 system.
4. The maximum performance level of the M-20 unit occurred in the range of 100 to 150 K, as reflected by comparison of the actual COP of the unit with the COP of a Carnot cycle refrigerator. The maximum performance was nearly 18% of a comparable Carnot cycle system.
5. The existence of a maximum in the COP/COP_{ideal} curve as a function of cooling head temperature indicates an optimal performance region and suggests the potential for design improvements when operating any such device at temperatures other than those specified.
6. The measured cool-down time to 77 K (10 minutes) is greater than that given (7.4 minutes) on the specification sheet. The manufacturer indicates that this difference was due primarily to the added thermal mass of the heater block assembly and the lower frequency characteristic associated with the equipment used in the tests of this study.

CONCLUDING REMARKS

The performance measurements of the M-20 unit obtained in the tests described herein are in essential agreement with manufacturer-supplied information.

Additional insight into the performance of the M-20 unit is gained by comparison with that of a Carnot device over its operating temperature range. Not only is its optimal operating condition clearly evident when viewed from such a perspective, but the potential for improving its performance is also evident. Such a perspective makes it clear that the design of such Stirling units for operation in another temperature range (e.g., as in domestic refrigerators) may require "tuning" to achieve optimal performance. If, for example, the performance of a Stirling refrigerator unit operating between 250 K (source) and 300 K (sink) could be improved from the 7.4% of Carnot reported here for the M-20 at those temperatures to the 17.8% of Carnot measured between 150 K and 300 K, the corresponding COP would rise from 0.37 to 0.89. If, as indicated by the manufacturer, further improvements might lead to achieving 25% of Carnot, the related COP would reach 1.25.

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APPENDIX I

**MANUFACTURER'S DESCRIPTION OF MODEL M-20
STIRLING CYCLE REFRIGERATOR**

Manufacturer: Cryodynamics, Inc.
191 Mill Lane
Mountainside, NJ 07092

Model: M-20

Serial No.: 1381

Volts: 230

Current: 60-Hz, 3-phase

Coolant: Air

CRYODYNAMICS, INC.

PRODUCT DATA NO. 120

MODEL M20

CRYOGENIC
REFRIGERATOR

Description

The Cryodynamics standard product line of miniature closed cycle cryogenic refrigerators are the most versatile, efficient, and reliable available for application to military, aerospace, and industrial high performance requirements.

The Model M20 requires less than 2000 watts input power to produce 110 watts net useable cooling at 77°K in 7.4 minutes with a minimum reliability of 1,000 hours continuous or ON/OFF operation. An integrated modified Stirling cycle 4 piston cryogenic engine. It uses helium as a working gas and operates at low pressure. Unique seal and mechanical design preclude requirements for lubrication, replenishment, or purging. Precise dynamic mechanical balancing results in very low vibration and acoustic noise. A specially designed high efficiency motor delivers the exact speed and torque required to optimize the input power to net useable cooling ratio. The temperature, capacity, cool-down time, and input power are variable; providing functional tailoring to a specific application operating condition. Its physical design flexibility facilitates ready adaptation to configuration requirements.

Cool-Down Time, t_{CD} (minutes)

Temperature (°K)

Net Cooling Capacity, Q_R (W)

Features

- High Efficiency
- Fast Cool-Down
- Reliable Maintenance Free Operation
- 60 Hz/400 Hz Air or Water Cooled
- MIL and NASA Spec. Compliance
- Hermetically sealed
- Custom Modification Adaptable

Applications

- IR Sensors and Lasers
- Range Instrumentation
- Low Noise Amplifiers and Antennae
- Process and Quality Control
- High Vacuum Cryo-Pumps
- Gas Liquefaction and Reliquefaction
- Vacuum Apparatus Cold Surfaces
- Electron Microscope Specimens

Specifications M20

Working Gas	Helium
Refrigerative Power (Net Useable)	110 W at 77°K
Cool-down Time	7.4 min. to 77°K
Input Power incl. Fan	1990 W at 77°K
Coolant	Air
Weight incl. Fan	65 lbs.
Power Required	400~3Ø 208V

NOTES:

- A. Helium fill valve and power electrical mating connectors, performance data, and operating manual supplied.
- B. Cold Head protective cover supplied in lieu of illustrated Vacuum Jacket. Standard shroud - 15 pounds.
- C. Fan selection may alter dimensions.
- D. Cryodynamics, Inc., whose policy is one of continuous product improvement, reserves the right to discontinue models or change specifications at anytime without incurring obligation.

CUSTOM MODIFICATION—BY QUOTATION

For information on additional standard models or CUSTOM MODIFICATION to your requirements, contact Cryodynamics

OPTIONAL ACCESSORIES:

- Temperature transducers
- Platinum resistor & mount (calibrated)
- End view window vacuum jacket
- Controls

cryodynamics, inc.

191 Mill Lane,
Mountainside, N.J. 07092
(201) 654-7700 • TWX 710-991-9553

1101 Bristol Road, Mountainside, N.J. 07092

(201) 654-7700 • TWX 710-991-9553 • FAX (201) 654-4981

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APPENDIX II
INSTRUMENTATION AND EQUIPMENT

Heater Unit Power Input

Current:

Micronta Digital Multimeter
 Range: Auto-Range
 Least Count - 0.01 Amps

Voltage: Speco Model FD-80
 Digital Multitester
 Range: 0-500 Volts
 Least Count - 0.1 Volts

Powerstat Variac

Type - 3PN136B
 Input V - 120 Volts
 Freq. - 50/60
 Single Phase
 Output voltage: 0-140 Volts
 Amps: 22
 KVA: 3.1

RTD Resistance Measurement

Keithley 177 Microvolt DMM
 UT No. - 368137
 Range: 0-999.99 Ohms
 Least Count: 0.01 Ohms

Fan Exit Air Temp.

Omega Thermocouple Thermometer (Type E) 450 AET
 Range: -215.0 F to 398.0 F
 Least Count - 0.1°F

Cryo-Unit Power Input Measurement

TIF Instruments, Inc.
 Watt Meter KW 220-3
 used with Copper Coils (Multiply Digital Readout by 0.1)
 Range: 0-999.9 kW (0-99.99 with multiplying factor)
 Least Count: 0.1 kW (0.01 with multiplying factor)

Vacuum Pump and Measurement

Master a-c Motor
 Serial No.: SF7352, Style: 133731
 Type: RA, Frame: 5835, HP: 1/3
 Volts: 115/230
 RPM - 1725

NRC Equipment Corporation
 Vacuum Gauge Control Type 701
 UT No. 142425
 Range: 0-1000 Microns
 Least Count: 5 Microns
 @ 0.62 A.C. Amps

Transformer to Boost From 208-230 V

Heavi-Duty Electric Co., Type HS (Quantity - 2)
 Catalog No. - H519F500 A
 Primary Volts - 120/240
 Secondary Volts - 12/24
 60 Hz, 1-Phase, 0.5 KVA

Platinum Resistance, K/°F/°C

<u>Temp. . . K</u>	<u>Res. . . Ω</u>	<u>Temp. . . °F</u>	<u>Temp. . . °C</u>
300	110.71	80.6	27
299	110.32	78.8	26
298	109.92	77.0	25
297	109.53	75.2	24
296	109.13	73.4	23
295	108.74	71.6	22
294	108.34	69.8	21
293	107.94	68.0	20
292	107.55	66.2	19
291	107.15	64.4	18
290	106.76	62.6	17
289	106.36	60.8	16
288	105.96	59.0	15
287	105.57	57.2	14
286	105.17	55.4	13
285	104.77	53.6	12
284	104.37	51.8	11
283	103.98	50.0	10
282	103.58	48.2	9
281	103.18	46.4	8
280	102.79	44.6	7
279	102.39	42.8	6
278	101.99	41.0	5
277	101.59	39.2	4
276	101.19	37.4	3
275	100.80	35.6	2
274	100.40	33.8	1
273	100.00	32.0	0
272	99.60	30.2	-1
271	99.20	28.4	-2
270	98.80	26.6	-3
269	98.41	24.8	-4
268	98.01	23.0	-5
267	97.61	21.2	-6
266	97.21	19.4	-7
265	96.81	17.6	-8
264	96.41	15.8	-9
263	96.01	14.0	-10
262	95.61	12.2	-11
261	95.21	10.4	-12
260	94.81	8.6	-13
259	94.41	6.8	-14
258	94.01	5.0	-15
257	93.61	3.2	-16
256	93.21	1.4	-17
255	92.81	-0.4	-18
254	92.41	-2.2	-19

Platinum Resistance, K/°F/°C

<u>Temp., K</u>	<u>Res., Ω</u>	<u>Temp., °F</u>	<u>Temp., °C</u>
253	92.01	-4.0	-20
252	91.61	-5.8	-21
251	91.21	-7.6	-22
250	90.81	-9.4	-23
249	90.40	-11.2	-24
248	90.00	-13.0	-25
247	89.60	-14.8	-26
246	89.20	-16.6	-27
245	88.80	-18.4	-28
244	88.40	-20.2	-29
243	87.99	-22.0	-30
242	87.59	-23.8	-31
241	87.19	-25.6	-32
240	86.79	-27.4	-33
239	86.39	-29.2	-34
238	85.98	-31.0	-35
237	85.58	-32.8	-36
236	85.18	-34.6	-37
235	84.77	-36.4	-38
234	84.37	-38.2	-39
233	83.97	-40.0	-40
232	83.56	-41.8	-41
231	83.16	-43.6	-42
230	82.76	-45.4	-43
229	82.35	-47.2	-44
228	81.95	-49.0	-45
227	81.55	-50.8	-46
226	81.14	-52.6	-47
225	80.74	-54.4	-48
224	80.33	-56.2	-49
223	79.93	-58.0	-50
222	79.52	-59.8	-51
221	79.12	-61.6	-52
220	78.71	-63.4	-53
219	78.31	-65.2	-54
218	77.90	-67.0	-55
217	77.50	-68.8	-56
216	77.09	-70.6	-57
215	76.68	-72.4	-58
214	76.28	-74.2	-59
213	75.87	-76.0	-60
212	75.47	-77.8	-61
211	75.06	-79.6	-62
210	74.65	-81.4	-63
209	74.25	-83.2	-64
208	73.84	-85.0	-65

Platinum Resistance, K/°F/°C

<u>Temp... K</u>	<u>Res... Ω</u>	<u>Temp... °F</u>	<u>Temp... °C</u>
207	73.43	-86.8	-66
206	73.02	-88.6	-67
205	72.62	-90.4	-68
204	72.21	-92.2	-69
203	71.80	-94.0	-70
202	71.39	-95.8	-71
201	70.99	-97.6	-72
200	70.58	-99.4	-73
199	70.17	-101.2	-74
198	69.76	-103.0	-75
197	69.35	-104.8	-76
196	68.94	-106.6	-77
195	68.53	-108.4	-78
194	68.13	-110.2	-79
193	67.72	-112.0	-80
192	67.31	-113.8	-81
191	66.90	-115.6	-82
190	66.49	-117.4	-83
189	66.08	-119.2	-84
188	65.67	-121.0	-85
187	65.26	-122.8	-86
186	64.85	-124.6	-87
185	64.43	-126.4	-88
184	64.02	-128.2	-89
183	63.61	-130.0	-90
182	63.20	-131.2	-91
181	62.79	-133.6	-92
180	62.38	-135.4	-93
179	61.97	-137.2	-94
178	61.55	-139.0	-95
177	61.14	-140.8	-96
176	60.73	-142.6	-97
175	60.32	-144.4	-98
174	59.90	-146.2	-99
173	59.49	-148.0	-100
172	59.08	-149.8	-101
171	58.66	-151.6	-102
170	58.25	-153.4	-103
169	57.84	-155.2	-104
168	57.42	-157.0	-105
167	57.01	-158.8	-106
166	56.59	-160.6	-107
165	56.18	-162.4	-108
164	55.76	-164.2	-109
163	55.35	-166.0	-110

Platinum Resistance, K/°F/°C

<u>Temp., K</u>	<u>Res., Ω</u>	<u>Temp., °F</u>	<u>Temp., °C</u>
162	54.93	-167.8	-111
161	54.52	-169.6	-112
160	54.10	-171.4	-113
159	53.69	-173.2	-114
158	53.27	-175.0	-115
157	52.86	-176.8	-116
156	52.44	-178.6	-117
155	52.02	-180.4	-118
154	51.61	-182.2	-119
153	51.19	-184.0	-120
152	50.77	-185.8	-121
151	50.35	-187.6	-122
150	49.93	-189.4	-123
149	49.52	-191.2	-124
148	49.10	-193.0	-125
147	48.68	-194.8	-126
146	48.26	-196.6	-127
145	47.84	-198.4	-128
144	47.42	-200.2	-129
143	47.00	-202.0	-130
142	46.58	-203.8	-131
141	46.16	-205.6	-132
140	45.74	-207.4	-133
139	45.32	-209.2	-134
138	44.90	-211.0	-135
137	44.48	-212.8	-136
136	44.06	-214.6	-137
135	43.64	-216.4	-138
134	43.22	-218.2	-139
133	42.80	-220.0	-140
132	42.37	-221.8	-141
131	41.95	-223.6	-142
130	41.53	-225.4	-143
129	41.10	-227.2	-144
128	40.68	-229.0	-145
127	40.26	-230.8	-146
126	39.83	-232.6	-147
125	39.41	-234.4	-148
124	38.99	-236.2	-149
123	38.56	-238.0	-150
122	38.14	-239.8	-151
121	37.71	-241.6	-152
120	37.29	-243.4	-153
119	36.86	-245.2	-154

Platinum Resistance, K/°F/°C

<u>Temp., K</u>	<u>Res., Ω</u>	<u>Temp., °F</u>	<u>Temp., °C</u>
118	36.43	-247.0	-155
117	36.01	-248.8	-156
116	35.58	-250.6	-157
115	35.15	-252.4	-158
114	34.73	-254.2	-159
113	34.30	-256.0	-160
112	33.87	-257.8	-161
111	33.44	-259.6	-162
110	33.02	-261.4	-163
109	32.59	-263.2	-164
108	32.16	-265.0	-165
107	31.73	-266.8	-166
106	31.30	-268.6	-167
105	30.87	-270.4	-168
104	30.44	-272.2	-169
103	30.01	-274.0	-170
102	29.58	-275.8	-171
101	29.15	-277.6	-172
100	28.72	-279.4	-173
99	28.29	-281.2	-174
98	27.85	-283.0	-175
97	27.42	-284.8	-176
96	26.99	-286.6	-177
95	26.56	-288.4	-178
94	26.12	-290.2	-179
93	25.69	-292.0	-180
92	25.25	-293.8	-181
91	24.82	-295.6	-182
90	24.39	-297.4	-183
89	23.95	-299.2	-184
88	23.52	-301.0	-185
87	23.08	-302.8	-186
86	22.65	-304.6	-187
85	22.21	-306.4	-188
84	21.78	-308.2	-189
83	21.34	-310.0	-190
82	20.91	-311.8	-191
81	20.47	-313.6	-192
80	20.04	-315.4	-193
79	19.60	-317.2	-194
78	19.17	-319.0	-195
77	18.74	-320.8	-196
76	18.31	-322.6	-197
75	17.88	-324.4	-198
74	17.45	-326.2	-199
73	17.02	-328.0	-200

Platinum Resistance, K/°F/°C

<u>Temp., K</u>	<u>Res., Ω</u>	<u>Temp., °F</u>	<u>Temp., °C</u>
72	16.59	-329.8	-201
71	16.16	-331.6	-202
70	15.73	-333.4	-203
69	15.31	-335.2	-204
68	14.88	-337.0	-205
67	14.46	-338.8	-206
66	14.03	-340.6	-207
65	13.61	-342.4	-208
64	13.19	-344.2	-209
63	12.77	-346.0	-210
62	12.36	-347.8	-211
61	11.95	-349.6	-212
60	11.54	-351.4	-213
59	11.13	-353.2	-214
58	10.72	-355.0	-215
57	10.32	-356.8	-216
56	9.92	-358.6	-217
55	9.53	-360.4	-218
54	9.14	-362.2	-219
53	8.75	-364.0	-220
52	8.37	-365.8	-221
51	7.99	-367.6	-222
50	7.62	-369.4	-223
49	7.25	-371.2	-224
48	6.89	-373.0	-225
47	6.53	-374.8	-226
46	6.18	-376.6	-227
45	5.84	-378.4	-228
44	5.50	-380.2	-229
43	5.17	-382.0	-230
42	4.85	-383.8	-231
41	4.54	-385.6	-232
40	4.24	-387.4	-233
39	3.94	-389.2	-234
38	3.66	-391.0	-235
37	3.38	-392.8	-236
36	3.12	-394.6	-237
35	2.87	-396.4	-238
34	2.62	-398.2	-239
33	2.39	-400.0	-240
32	2.17	-401.8	-241
31	1.96	-403.6	-242
30	1.76	-405.4	-243
29	1.58	-407.2	-244
28	1.41	-409.0	-245

Platinum Resistance, K/°F/°C

<u>Temp., K</u>	<u>Res., Ω</u>	<u>Temp., °F</u>	<u>Temp., °C</u>
27	1.25	-410.8	-246
26	1.10	-412.6	-247
25	0.96	-414.4	-248
24	0.84	-416.2	-249
23	0.73	-418.0	-250
22	0.63	-419.8	-251
21	0.54	-421.6	-252
20	0.46	-423.4	-253
19	0.39	-425.2	-254
18	0.33	-427.0	-255
17	0.28	-428.8	-256
16	0.23	-430.6	-257
15	0.20	-432.4	-258
14	0.17	-434.2	-259
13	0.14	-436.0	-260
12	0.12	-437.8	-261

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