What is the Age of the Milky Way?

Student Guide

Explore: How fast does water cool?

Safety Warning: your group will be working with hot water that could burn your skin. Take care when making temperature measurements of the water.

1. The materials manager from each group should collect materials and a cup of hot water marked to one of the three levels: 100 ml, 200 ml, or 300 ml.

2. Use the graph template called "Water Cooling".

Observations: Measure the temperature over a 10-minute time interval

1. Record the initial temperature of the water and begin the stopwatch.
2. Record the temperature of the water at 20-second intervals.
3. Plot the temperature vs. time on the graph paper.
4. Record the final temperature after 10 minutes have elapsed.

3. Each group will present their plot to the rest of the class. Before your presenter shows your group's results, make a list questions you would like to ask each group.

4. What methods of energy transport for heat do you think are at work in your experiment?

5. What do you think are the main variables in your experiment?

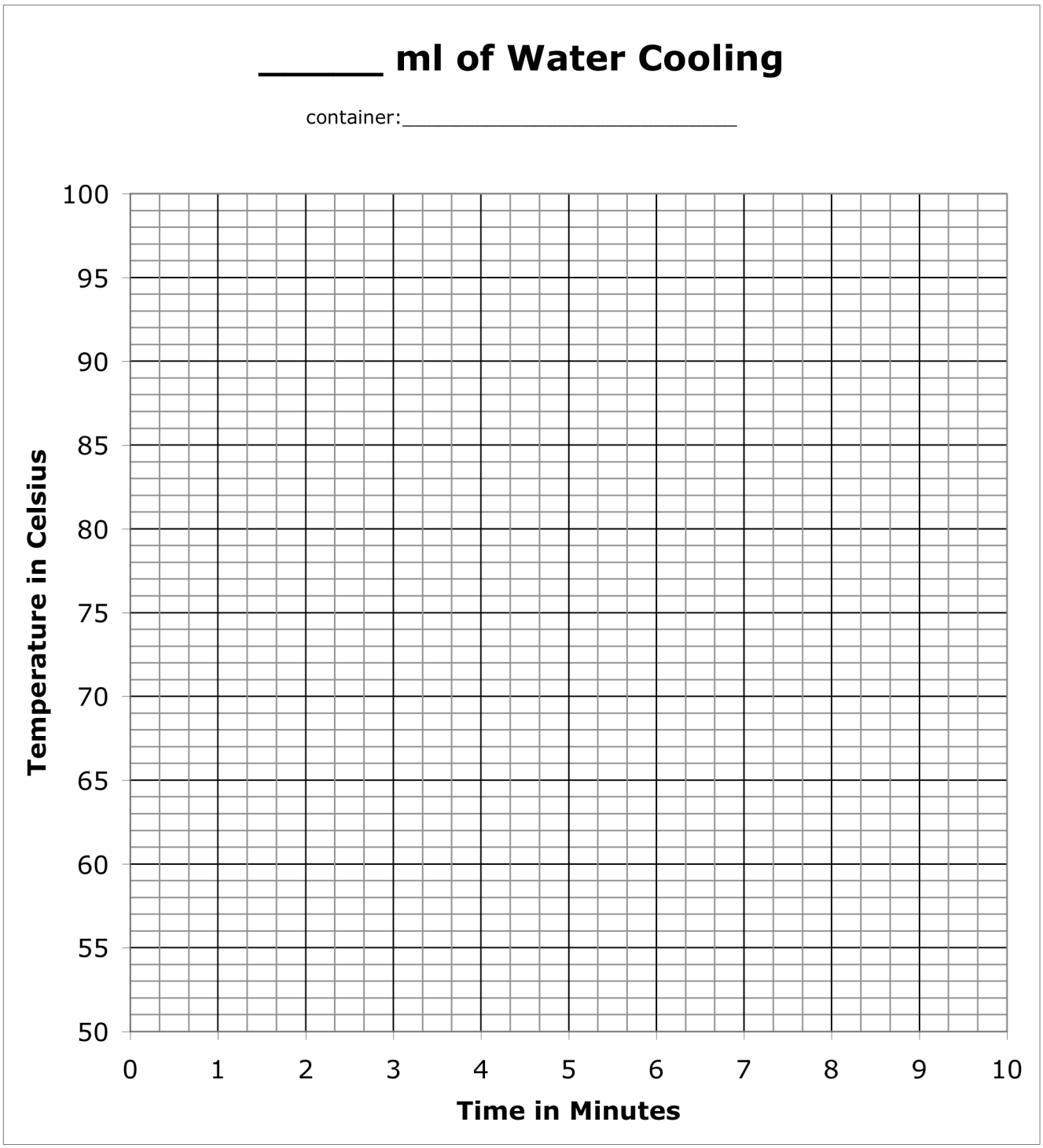
6. Does the precision and accuracy of your estimate change with cooling time? If so, explain how and also explain why you think this happens.

Data Table

How fast does the water cool?

Water Volume:_____ Initial Temperature:_____

Temperature Celsius	**Time** minute



Data Table

When was the hot water added to the cups?

Cup	Water Volume (ml)	Observed Temperature C	Predicted Time	Notes
	100			
	200			
	300			

Randomly Selected White Dwarfs

Data from Table 1 in Kilic, Mukremin, et al. *Cool White Dwarfs in the Sloan Digital Sky Survey* 2005.

Catalog Name	Name	Type	Effective Temperature	Bolometric Magnitude
00 11 42.6 -09 03 24.3	WD 1	DA	6125	13.97
00 45 21.88 +14 20 45.3	WD 2	DZA	4732	15.11
01 15 14.73 +14 35 57.5	WD 3	DA	6320	13.84
01 59 38.43 -08 12 42.4	WD 4	DA	8214	12.69
02 56 41.62 -07 00 33.8	WD 5	DC	4211	15.62
03 14 49.81 -01 05 19.3	WD 6	DA	5709	14.29
04 06 32.39 -04 32 50.4	WD 7	DA	6624	13.63
07 53 13.28 +42 30 01.6	WD 8	DC	4226	15.61
08 20 56.07 +48 03 52.9	WD 9	DA	6388	13.79
08 36 41.36 +45 56 58.7	WD 10	DC	4373	15.46
09 19 48.92 +01 15 53.0	WD 11	DA	6227	13.9
09 42 44.94 +44 37 43.1	WD 12	DC	4052	15.79
10 02 25.85 +61 08 58.1	WD 13	DC	3581	16.33
10 11 05.63 +00 29 44.4	WD 14	DAH	6184	13.93
10 23 56.10 +63 48 33.8	WD 15	DA	6243	13.89
11 11 54.54 +03 27 26.2	WD 16	DA	5899	14.14
11 19 40.62 -01 07 55.1	WD 17	DC	4283	15.55
11 44 39.54 +66 29 28.5	WD 18	DAH	6919	13.44
12 02 00.48 -03 13 47.4	WD 19	DC	4151	15.69
12 05 29.15 +04 49 35.6	WD 20	DC	5524	14.43
12 34 08.12 +01 09 47.4	WD 21	DA	5177	14.72
13 00 21.25 +01 30 45.5	WD 22	DA	5297	14.61
12 13 13.12 +02 26 45.8	WD 23	DC	3394	16.56
13 39 39.55 +67 04 49.8	WD 24	DA	6409	13.78
14 26 59.40 +49 21 00.6	WD 25	DC	6927	13.43
15 55 34.18 +50 25 47.8	WD 26	DA	6204	13.92
16 23 24.05 +34 36 47.7	WD 27	DA	7650	13
16 48 47.07 +39 39 17.0	WD 28	DC	5401	14.53
17 04 47.70 +36 08 47.4	WD 29	DC	4560	15.28
17 24 13.32 +27 56 55.2	WD 30	DA	6131	13.97
20 41 28.99 +00 37 34.4	WD 31	DA	4673	15.17
20 45 06.97 +00 37 34.4	WD 32	DA	6093	14
21 16 40.30 -07 24 52.7	WD 33	DC	4359	15.47
21 25 01.48 -07 34 56.0	WD34	DA	6063	14.02
21 54 30.69 +13 00 26.7	WD 35	DZA	4768	15.08
22 41 57.63 +13 32 38.8	WD 36	DA	5986	14.07
22 54 08.64 +13 23 57.2	WD 37	DC	3356	16.61
23 30 40.47 +01 00 47.4	WD 38	DA	6768	13.54
23 40 41.47 -11 06 36.9	WD 39	DA+M	6612	13.64
23 54 16.59 +00 30 01.2	WD 40	DA	5298	14.61

Legend for White Dwarf Spectral Types: These are classifications of white dwarfs based on their spectra.

- DA, DAH — thin hydrogen atmosphere. Its spectrum looks like an A-type star, which shows strong hydrogen absorption features.
- DA+M — a binary star system with a DA type white dwarf and M type star.
- DB — helium atmosphere, showing only helium absorption features in its spectrum.
- DC — shows no absorption features in its spectrum.
- DZA — shows hydrogen (H) strongly, ionized calcium (Ca), magnesium (Mg), iron (Fe), and sometimes sodium (Na).

Explain

1. Compare your water cooling curve and the other cooling curves of everyday things to the white dwarf cooling curve. What are the similarities and differences?

2. Examine the plot of the white dwarfs on the white dwarf cooling curve.

a. Where are most of the white dwarfs located on the plot?

b. Where are the oldest white dwarfs?

3. Which white dwarfs do you think are the brightest? Why?

Explain

4. How fast you think the luminosity of the white dwarf changes compared to the temperature? Calculate the luminosity ratio for a white dwarf at 10,000 K and 4,000 K compared to a white dwarf at 20,000 K. For example, $L_1/L_2 = (20{,}000 / 10{,}000)^4$

Temperatures	Luminosity Ratio L_1/L_2	Temperature Ratio T_1/T_2
$T_1 = 20{,}000$ $T_2 = 10{,}000$		
$T_1 = 20{,}000$ $T_2 = 4{,}000$		

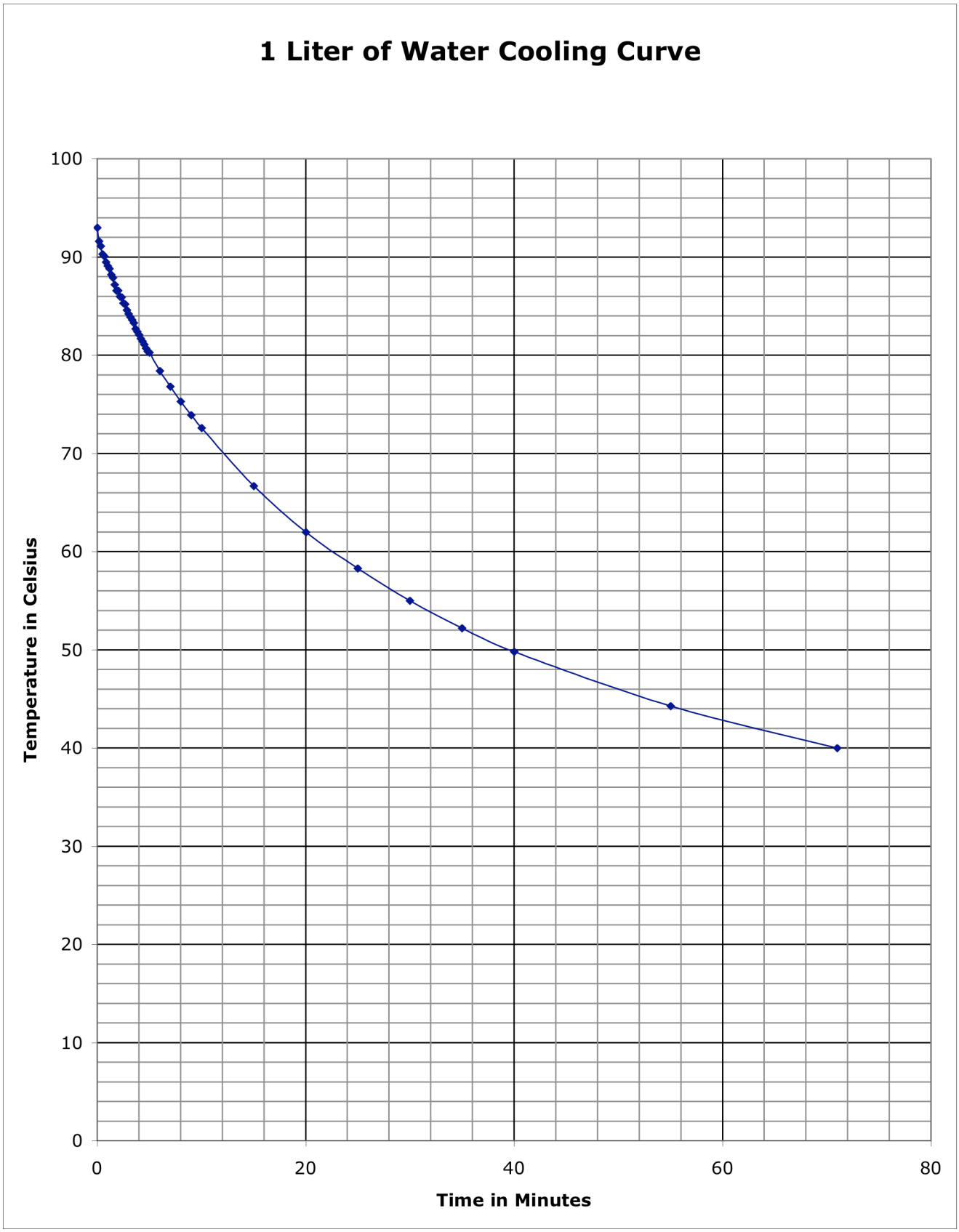
5. What could explain the cool white dwarf drop-off, where you don't see any cooler than about 3,600 Kelvin?

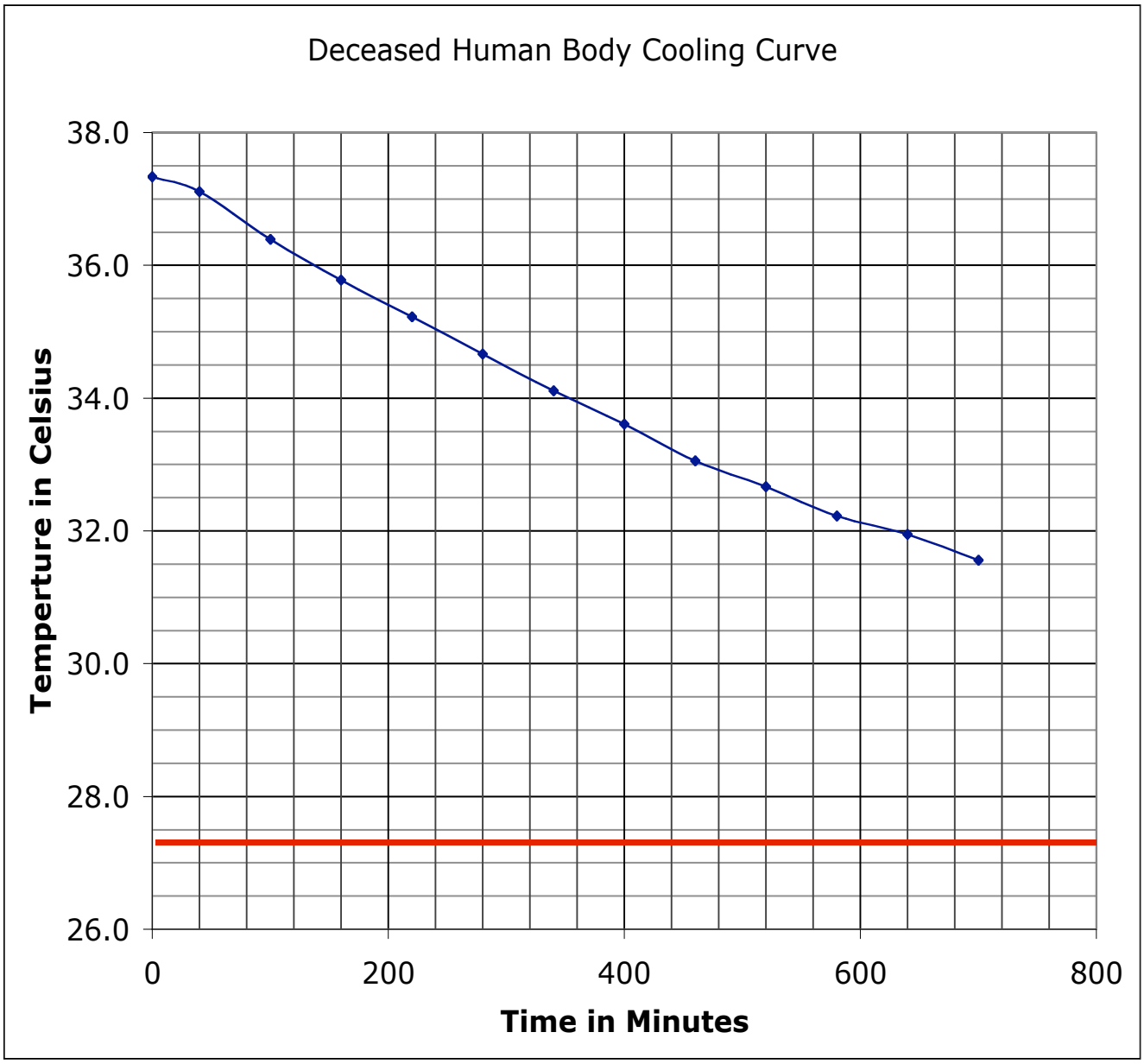
6. If you actually have the ability to detect white dwarfs beyond the drop-off, what conclusions can you draw from this data about the age of our galaxy?

Elaborate: Improving the Calculation for the Age of our Galaxy

You are an astronomer who wants to improve the calculations for the age of our galaxy based on white dwarf stars. What are some simple ways to improve the accuracy and precision of the calculation?

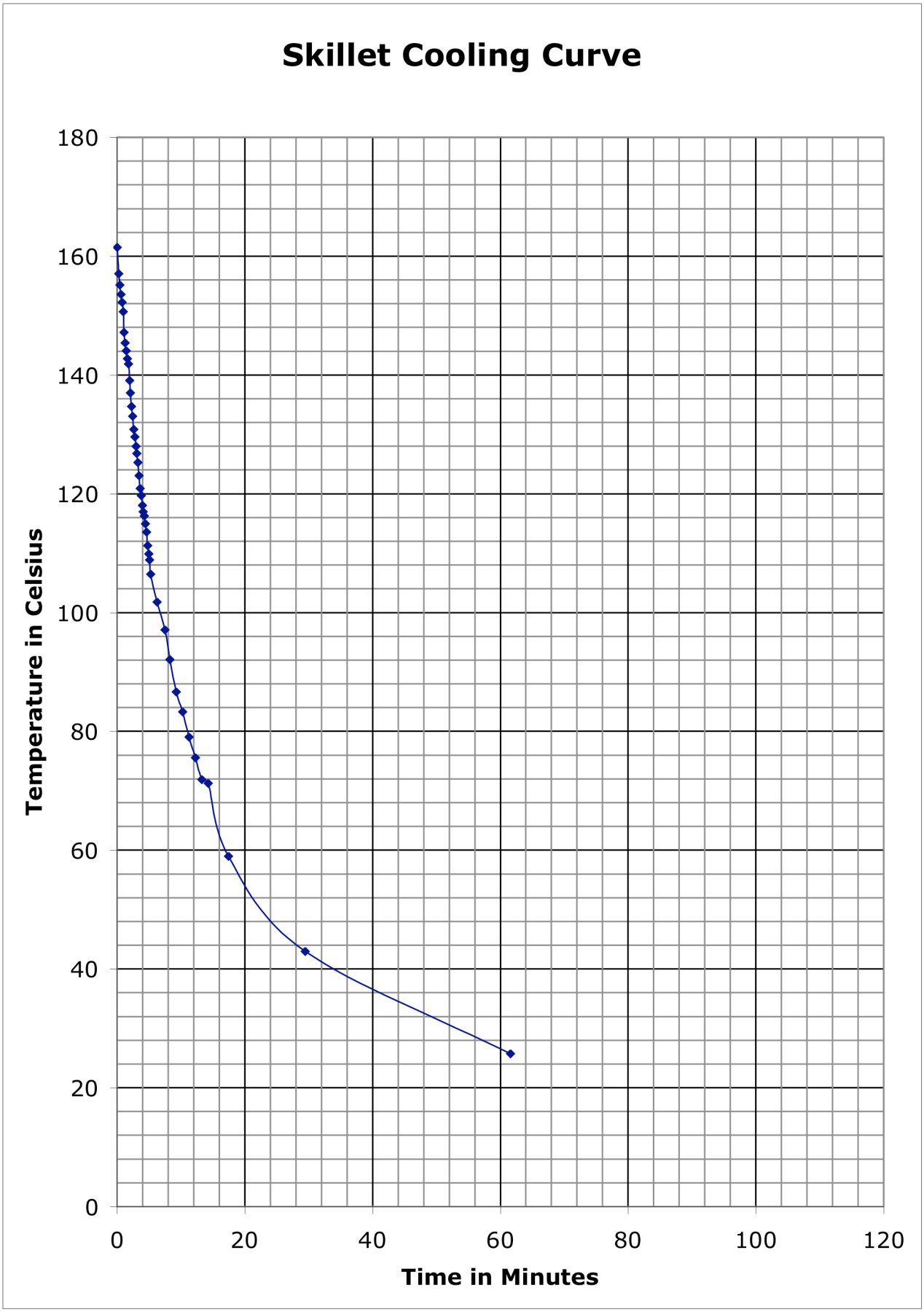
Idea	Priority	Evaluation

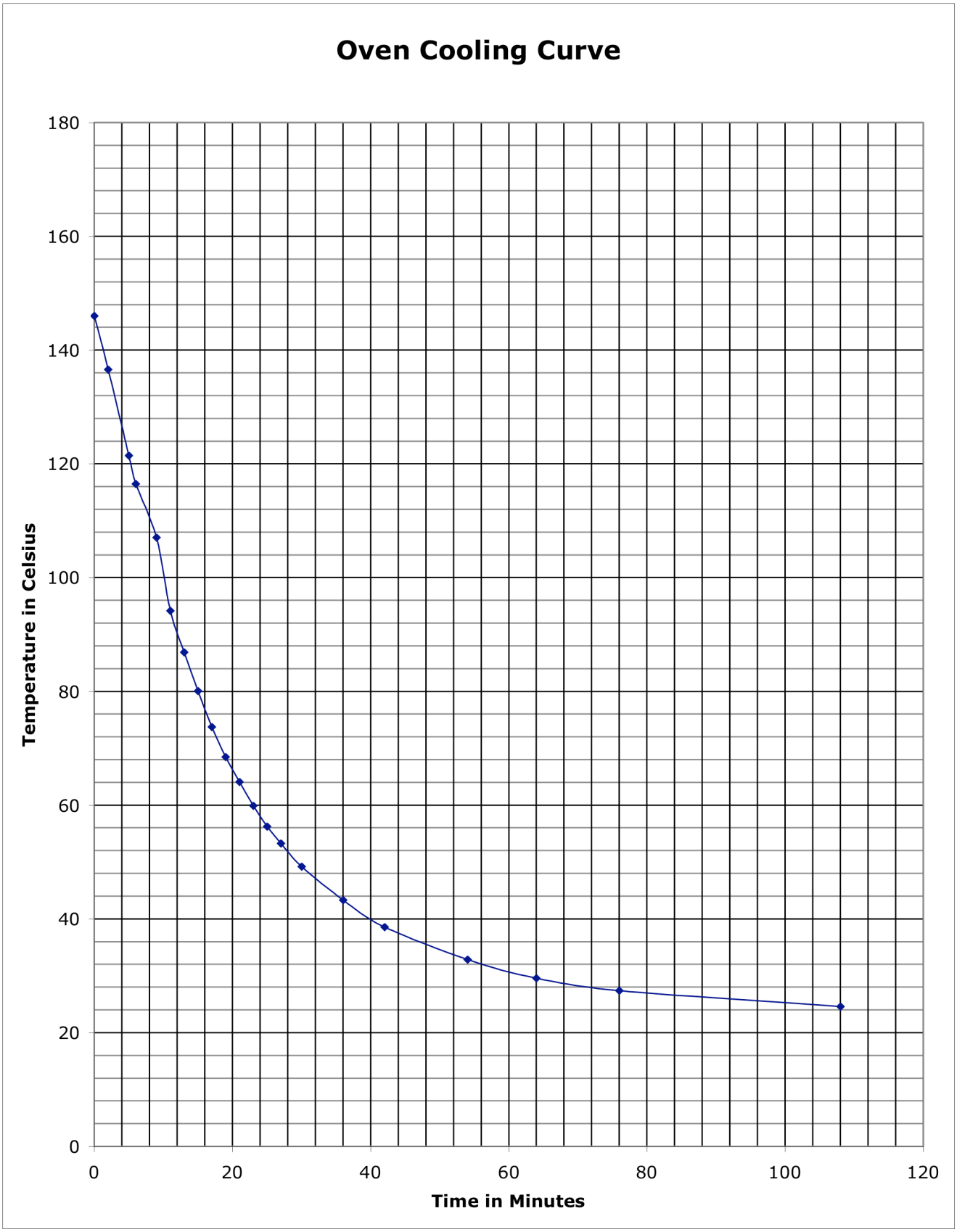


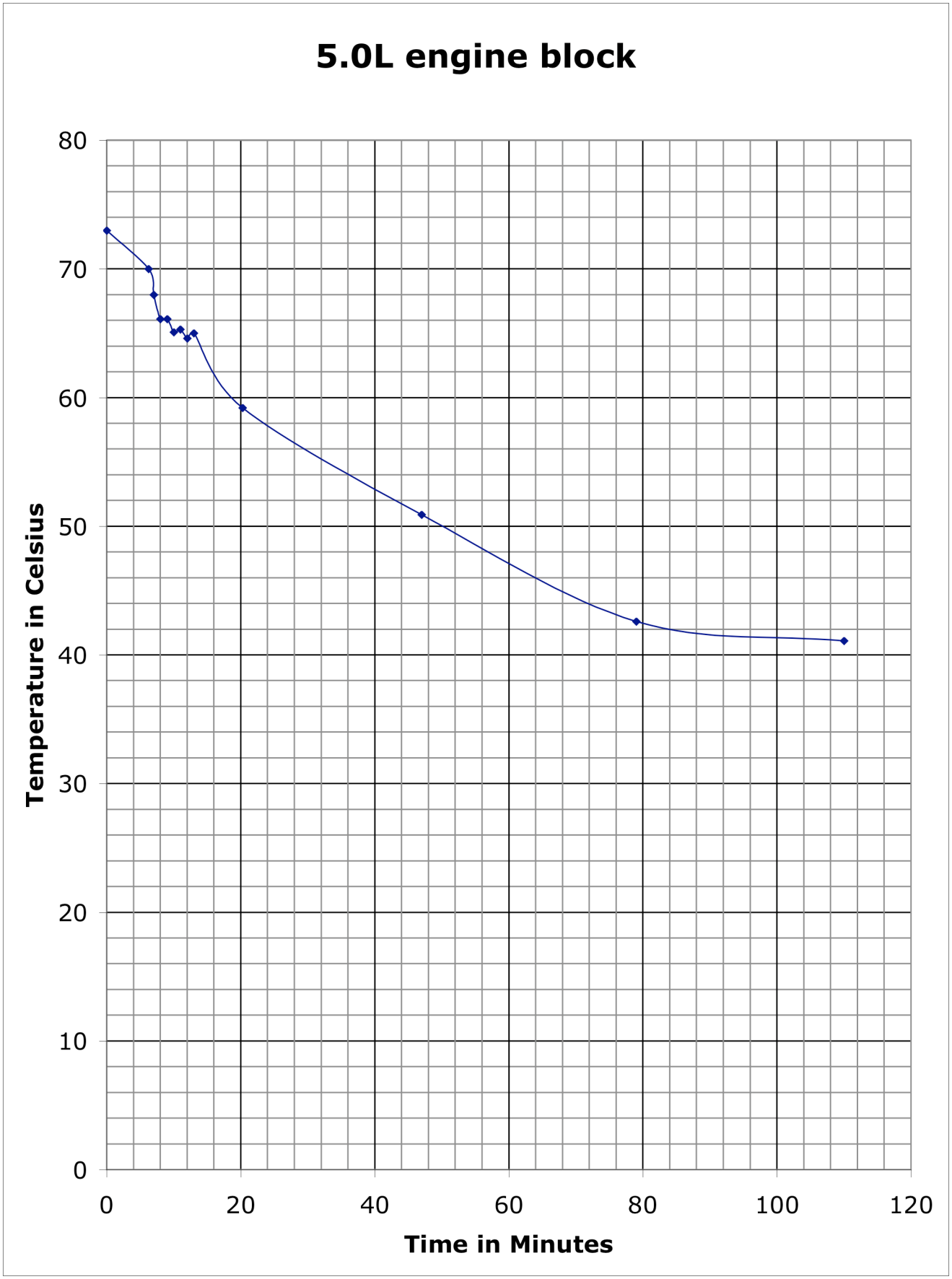


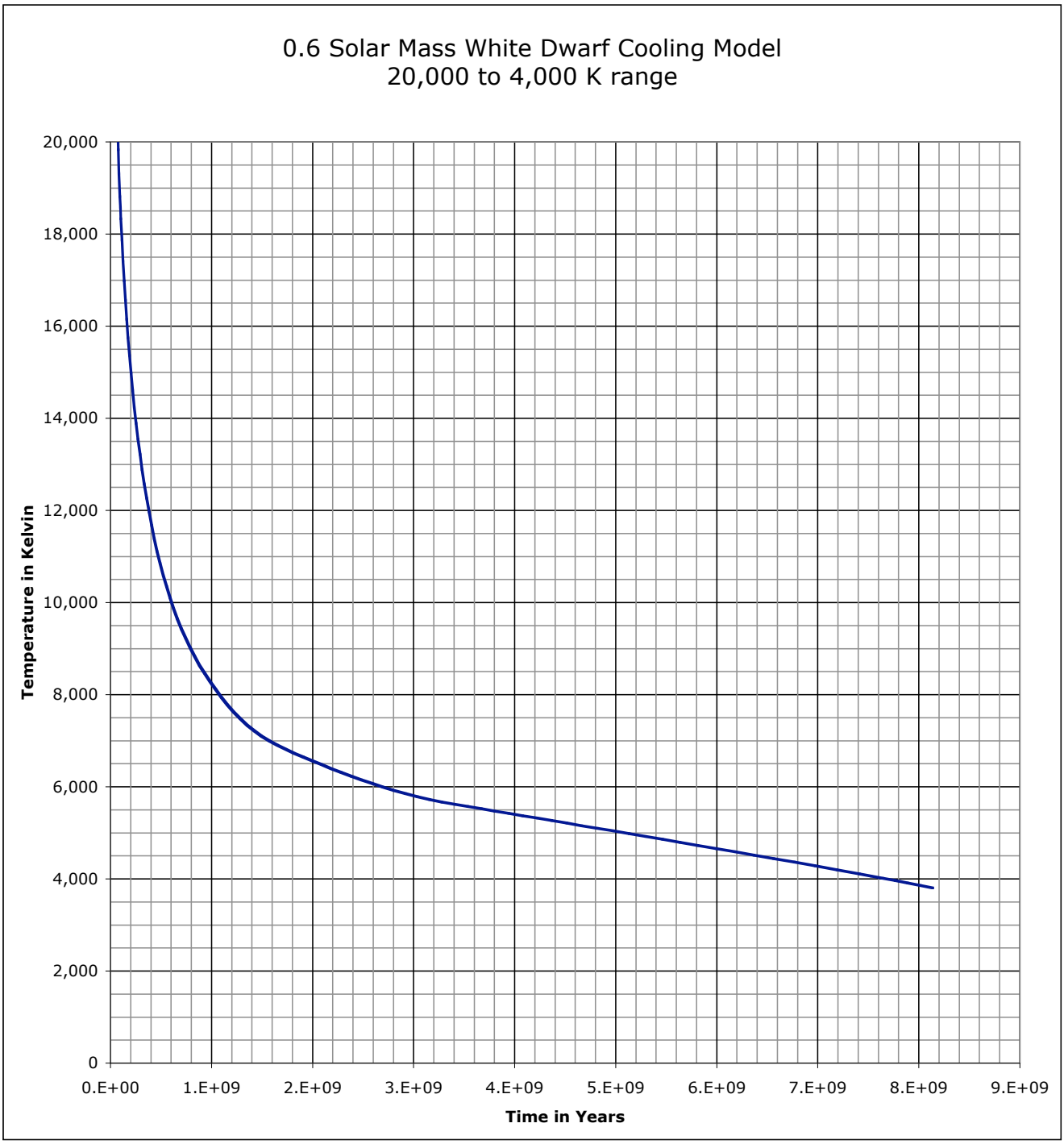
Average laboratory temperature = 27.3 ^{o}C

Source:
Post-Mortem Temperature and the Time of Death
G.S.W. de Saram; G. Webster; N. Kathirgamatamby
The Journal of Criminal Law, Criminology, and Police Science, Vol. 46, No. 4 (Nov. –Dec., 1955), p. 562-577.









Note: 1.E+09 is 10^9 or one billion (1,000,000,000) years.

Investigating models of white dwarf cooling

1. Lay the transparency film over the white dwarf cooling curve.
2. Place a dot at the origin.
3. Trace the x- and y-axis on the transparency film.
4. Plot the white dwarf data on the transparency film using white dwarf cooling graph as a guide.

