Lab
4

Solar Radiation & Temperature

The purposes of this lab are to:1) continue with the concepts of solar altitude angle and show how it has a direct relationship with air temperature; and 2) familiarize the student with reasons for different air temperatures around the world due to the Earth-Sun relationship and changing sun angles.

Insolation

Insolation (short wave radiation from the Sun) is the primary source of energy in the Earth's environment even though the Earth intercepts only a very small portion of the total energy emitted by the Sun. While the amount of insolation reaching the outer edge of the Earth's atmosphere is fairly constant, the amounts of such energy reaching the ground vary with different times and locations.

The intensity of insolation at the Earth's surface is affected by many variables, such as:

1) The sun angle above the horizon,
2) Length of period of sunlight exposure,
3) Existing atmospheric conditions, and
4) Amount of reflection, scattering, and absorption of Solar rays by the Earth's atmosphere.

Incoming short-wave energy from both the direct solar beam and indirect sky radiation are simultaneously measured with an instrument known as a **pyranometer**. The intensity of solar radiation calculated by the pyranometer is in a unit of measurement called **langleys**. A langley constitutes a unit of heat energy having one gram calorie per square centimeter. (A **calorie** is the amount of heat needed to raise the temperature of one gram of water by one degree **Celsius**.)

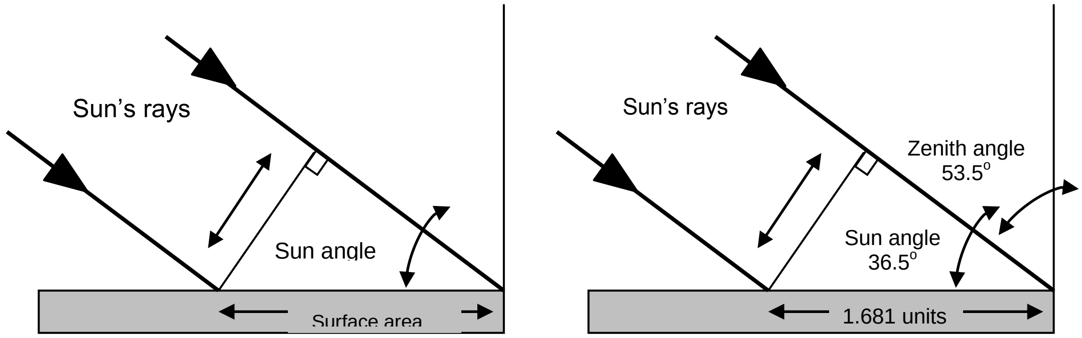
The **solar constant*** is the average intensity of vertical rays of solar energy striking a flat surface at the top of the Earth's atmosphere. Its value is approximately 2.0 langleys per minute. As solar energy passes through the atmosphere, some of it is lost due to absorption and scattering causing the intensity to drop below 2.0 langleys.

* Also expressed as 2 gram calories per centimeter^2 per minute.

Calculating Solar Intensity

Sun angle (Altitude Angle) is very important because it affects the intensity of solar radiation reaching the ground. When altitude angles are large (i.e. closer to 90°) solar rays are more direct. As altitude angle decreases, radiation is spread over a larger surface area. When more surface area "shares" the solar energy, the intensity of the energy received is less.

Figure 4.1 Solar Angle and Surface Area



Determining the surface area of solar radiation

The surface area that the beam of solar radiation covers changes with the solar altitude angle and can be determined through trigonometry. The following equations are used to determine the surface area:

$$\sin(\text{altitude angle}) = \frac{\text{1 unit width}}{\text{surface area}} \qquad \text{surface area} = \frac{1}{\sin(\text{altitude angle})}$$

For example, if the altitude angle = 50°.

$$\text{surface area} = \frac{1}{\sin(50°)} = \frac{1}{0.766} = 1.305$$

This means that 1 unit area of sunshine striking the earth with an altitude angle of 50° will be spread over an area of 1.305 (i.e. an area 30.5% larger). As solar radiation is spread over more of the Earth's surface, the intensity of the beam decreases according to the following equation:

Percent of beam intensity = sin(altitude angle) * 100

For example, if the altitude angle = 50°; sin(50°) = 0.766 (100 * 0.766 = 76.6) or 76.6%.

Internet Resources for Solar Radiation & Temperature

1. USA Today Temperature Conversions
http://www.usatoday.com/weather/wtempcf.htm

2. USA Today Heat Index Wind Chill
http://www.usatoday.com/weather/wheat3.htm
http://www.usatoday.com/weather/windchil.htm

4. This web site calculates average monthly sun angle of any latitude on the Earth:
http://www.wattsun.com/resources/calculators/photovoltaic_tilt.html

Exercise #4 Lab Activity Name: ______________________________

Solar radiation & Temperature Lab Section: ______________________________

Please show your work. If necessary please use additional paper to show work.

Part B: Fill in the blanks below based on the formulas above.

Place	Latitude of Place	Latitude of Vertical Ray	Zenith Angle	Altitude Angle	Surface Area of Radiation	% of Beam Intensity
1. Salem, MA	**43° N**	**0°**	**43°**	**47°**	**1.367**	**73%**
2. Salem, MA	_____	23.5° N	_____	_____	_________	_________
3. Salem, MA	_____	23.5° S	_____	_____	_________	_________
4. Barrow	71° N	23.5° N	_____	_____	_________	_________
5. Barrow	_____	0°	_____	_____	_________	_________
6. Barrow	_____	23.5° S	_____	_____	_________	_________
7. Singapore	1° N	23.5° N	_____	_____	_________	_________
8. Singapore	_____	0°	_____	_____	_________	_________
9. Singapore	_____	23.5° S	_____	_____	_________	_________
10. Cape Town	34° S	23.5° N	_____	_____	_________	_________
11. Cape Town	_____	0°	_____	_____	_________	_________
12. Cape Town	_____	23.5° S	_____	_____	_________	_________
13. Vostok	79° S	23.5° N	_____	_____	_________	_________
14. Vostok	_____	0°	_____	_____	_________	_________
15. Vostok	_____	23.5° S	_____	_____	_________	_________

The Balance Between Insolation & Air Temperature

The following section illustrates the relationship between mean monthly insolation values and mean monthly air temperature for the Boston area.

Table 4.1

MEAN MONTHLY INSOLATION – BOSTON AREA

Solar radiation in Langleys/day

Jan.	139	Apr.	364	July	496	Oct.	238
Feb.	198	May	472	Aug.	425	Nov.	145
Mar.	293	June	499	Sept.	341	Dec.	119

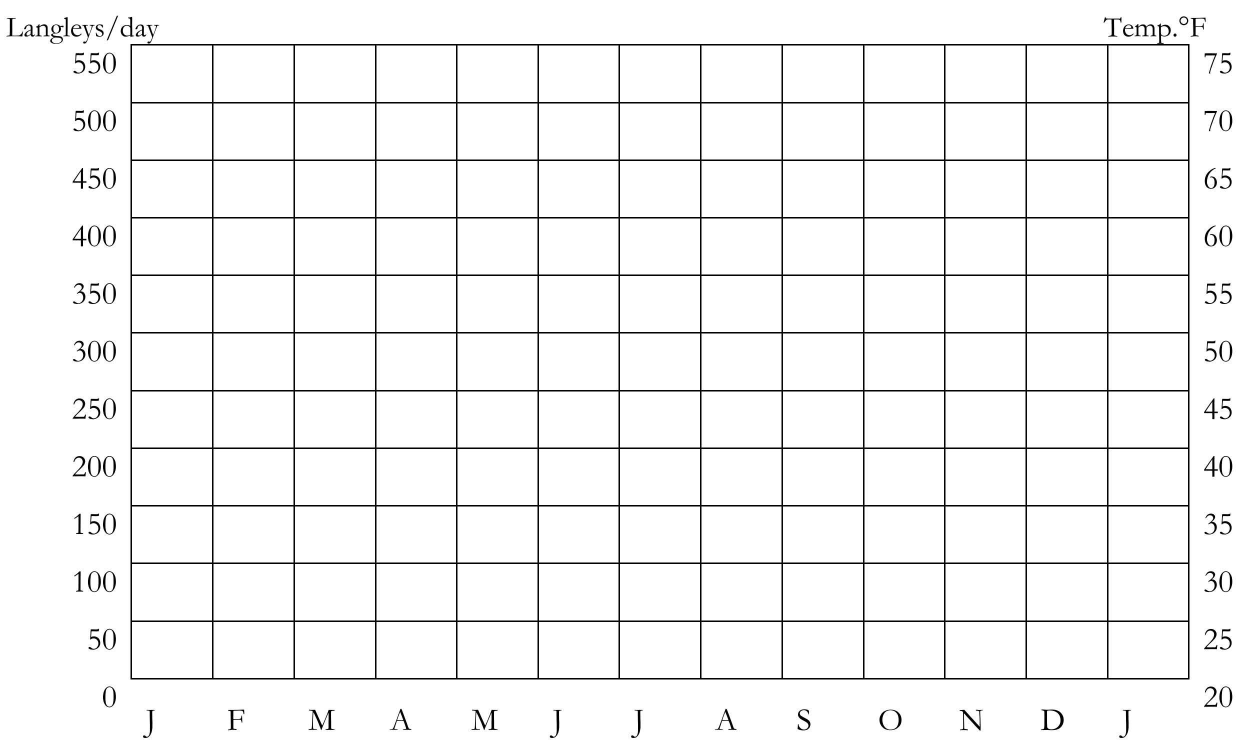
Table 4.2

MEAN MONTHLY AIR TEMPERATURE – BOSTON AREA

Temperature in degrees Fahrenheit

Jan.	27	Apr.	45	July	72	Oct.	52
Feb.	28	May	57	Aug.	69	Nov.	41
Mar.	35	June	68	Sept.	63	Dec.	32

<u>Mean Monthly Solar Radiation and Temperature Graph</u>



✐Plot the following information on the graph provided:

a. Plot the *insolation values* (solar radiation) from Table 4.1 using the left side of the graph for each month of the year. After plotting, connect all the points with a smooth, curved line.

b. Plot the *temperature values* from Table 4.2 using the right side of the graph for each month of the year. After plotting, connect these points with a smooth, dashed line.

After carefully analyzing the relationship illustrated by the lines you have graphed for Insolation and Air Temperature, answer the following:

✐16. Describe the pattern of the insolation curve in terms of *minimum* and *maximum* values during the course of the twelve months of the year.

✐17. Based on the graph and your understanding of sun angles from the prior lab, what is the relationship between insolation values and sun angles during the year?

✐18. Briefly describe the pattern of *mean air temperature values* in terms of minimum and maximum values during the year.

✐19. Compare the *insolation curve* to the *air temperature curve*. How does the *pattern* differ between the two? (Keep in mind that air temperature is ultimately a result of incoming solar radiation.)

✐20. Explain why the difference occurs between the air temperature and insolation curves. That is, why is there a lag in the temperature curve? (This is related to the *direct* source of energy heating the air.)

Specific Heat of Land and Water; Continental and Maritime Effects

The **specific heat** of a substance is the amount of heat energy required to raise the temperature of 1 gram of that substance by 1 degree Celsius. If we generalize about the surface of the earth, we might say that all water areas have a Specific Heat of 1.0 (Cal/g x °C) and all land areas exhibit a Specific Heat of 0.5 (Cal/g x °C). The significance of this fact is that land areas will heat up more quickly and cool off more quickly than water areas and that water areas will take longer to become warm and longer to cool off.

In addition, if land and water areas were recorded as having the same temperature, the water area would be holding considerably more heat since it required more heat energy to get to that temperature than for the land area. The foregoing information leads to the concepts of **continental** and **marine** (Maritime) climate effects.

Land areas in the mid-latitudes (Westerly wind belt) that are on the windward side of a large water body will experience moderation in temperatures especially during winter and summer; whereas areas that are surrounded by large expanses of land (interior of continents) will exhibit extreme conditions of temperature in winter and summer.

Using the mean monthly temperature data listed below, plot temperature curves for Denver, CO, Springfield, MO, and San Francisco, CA on the graph on the following page. Use a solid line for Denver (——), a dashed line (– – –) for Springfield, and a dash and dot line (– · – · –) for San Francisco.

Place	Elevation	Latitude	Mean Annual Air Temperature
DENVER, CO	5,292'	39° 32' N	50 ° F
SPRINGFIELD, MO	1,324'	37° 17' N	56 ° F
SAN FRANCISCO, CA	8'	37° 27' N	55° F

	J	F	M	A	M	J	J	A	S	O	N	D
DENVER	30	32	39	47	56	66	72	71	62	50	39	33
SPRINGFIELD	34	35	45	56	64	73	77	76	70	58	46	36
SAN FRANCISCO	49	51	53	54	56	57	57	58	60	59	56	51

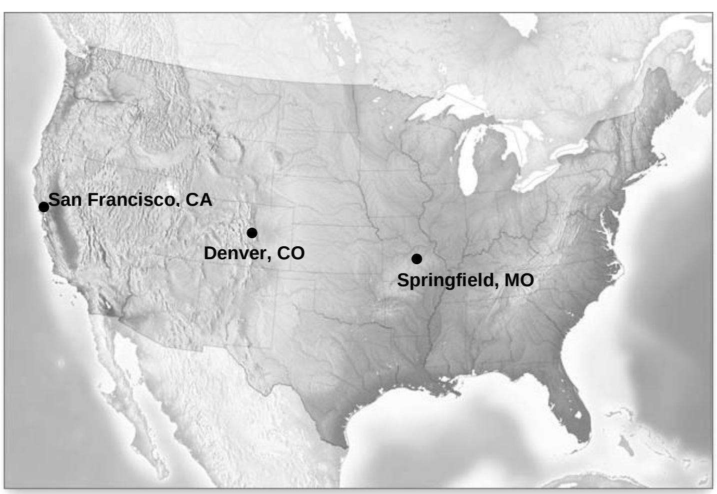
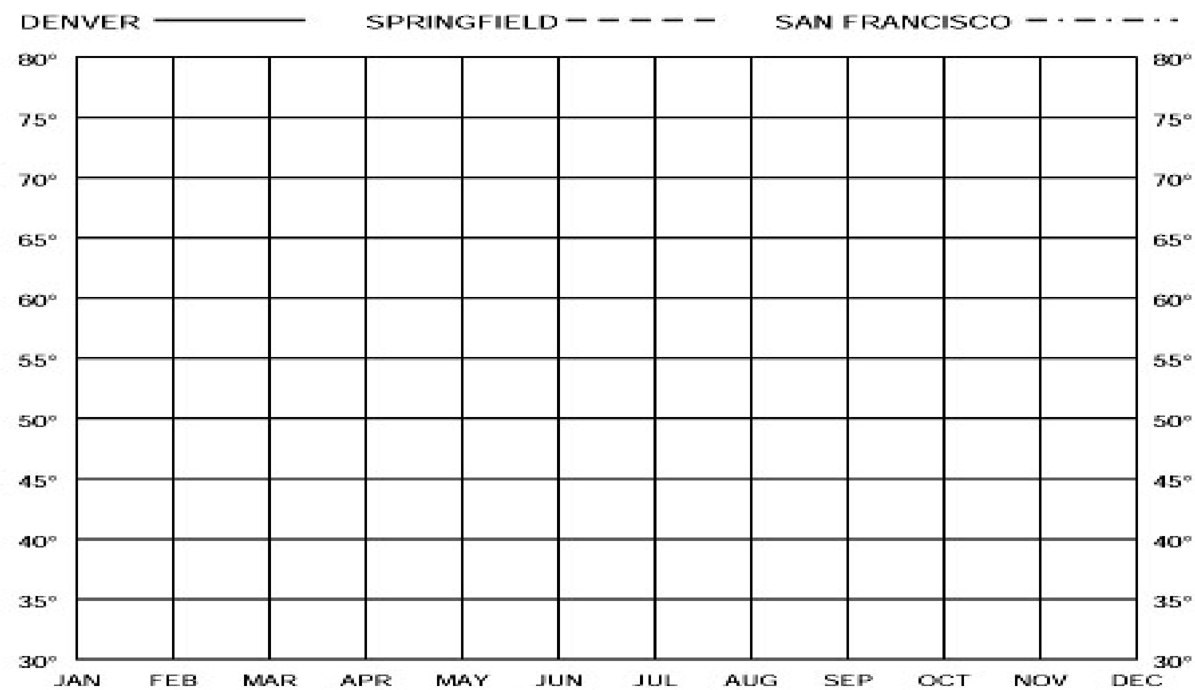


Figure 4.2
Map of city locations

TEMPERATURE CHART FOR DENVER, SPRINGFIELD, AND SAN FRANCISCO



After analyzing each temperature curve on the graph and comparing it to the information on elevation, latitude, and mean annual temperature, answer the following questions.

✐21. Which of the three cities has the greatest variation in annual range of temperature? Explain the factors accounting for this.

✐22. Compare San Francisco's temperature curve with those of Denver and Springfield. Describe the differences in the San Francisco curve.

✐23. Why is Denver always slightly cooler than Springfield?

✐24. Explain the factors that influence the San Francisco curve. (Note: next to San Francisco there is a cold ocean current, especially in summer.)

✐25. For each of the three cities, determine the month in which the maximum temperature occurs. Explain why the maximum occurs at this time in each case.

Temperature Scales and Conversions

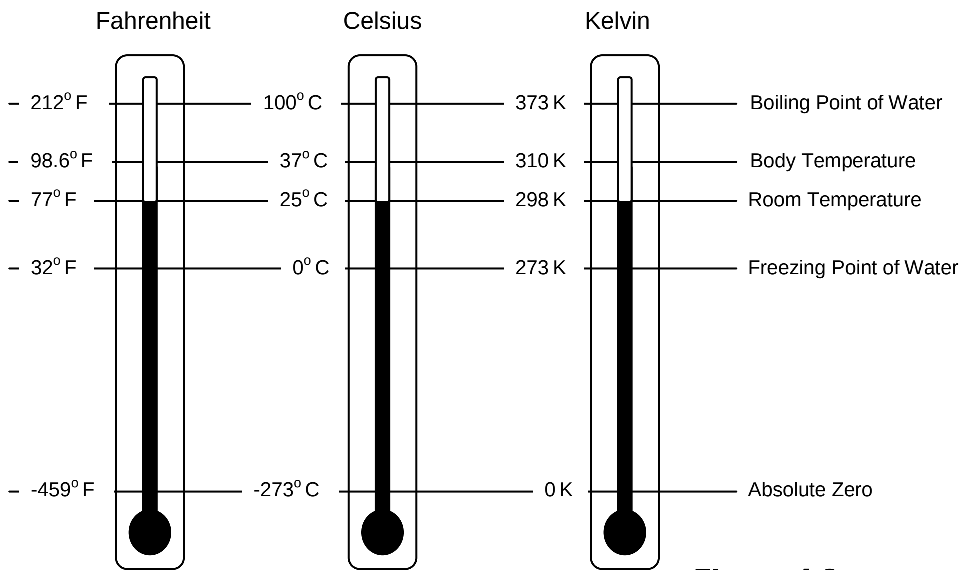


Figure 4.3

Figure 4.3 shows the most common temperature scales and shows how they relate to each other based on several important temperatures such as the freezing point of water.

To convert from one temperature scale to another, use the following:

$$°Fahrenheit = (1.8 \times °C) + 32 \qquad °Celsius = \frac{°F - 32}{1.8} \qquad °Kelvin = °C + 273$$

✐26. Convert the following Fahrenheit temperatures to Celsius.

a. 25 °F =

b. 92 °F =

✐27. Convert the following Celsius temperatures to Fahrenheit.

a. 15 °C =

b. 50 °C =

✐28. Convert 45 °F to Kelvin.

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Angle	Sin Θ
0	**0.000**
2	0.035
4	0.070
6	0.105
8	0.139
10	0.174
12	0.208
14	0.242
16	0.276
18	0.309
20	0.342
22	0.375
24	0.407
26	0.438
28	0.469
30	**0.500**
32	0.530
34	0.559
36	0.588
38	0.616
40	0.643
42	0.669
44	0.695
46	0.719
48	0.743
50	0.766
52	0.788
54	0.809
56	0.829
58	0.848
60	**0.866**
62	0.883
64	0.899
66	0.914
68	0.927
70	0.940
72	0.951
74	0.961
76	0.970
78	0.978
80	0.985
82	0.990
84	0.995
86	0.998
88	0.999
90	**1.000**

Angle	Sin Θ
0.5	0.009
2.5	0.044
4.5	0.078
6.5	0.113
8.5	0.148
10.5	0.182
12.5	0.216
14.5	0.250
16.5	0.284
18.5	0.317
20.5	0.350
22.5	0.383
24.5	0.415
26.5	0.446
28.5	0.477
30.5	0.508
32.5	0.537
34.5	0.566
36.5	0.595
38.5	0.623
40.5	0.649
42.5	0.676
44.5	0.701
46.5	0.725
48.5	0.749
50.5	0.772
52.5	0.793
54.5	0.814
56.5	0.834
58.5	0.853
60.5	0.870
62.5	0.887
64.5	0.903
66.5	0.917
68.5	0.930
70.5	0.943
72.5	0.954
74.5	0.964
76.5	0.972
78.5	0.980
80.5	0.986
82.5	0.991
84.5	0.995
86.5	0.998
88.5	1.000

Angle	Sin Θ
1	0.017
3	0.052
5	0.087
7	0.122
9	0.156
11	0.191
13	0.225
15	0.259
17	0.292
19	0.326
21	0.358
23	0.391
25	0.423
27	0.454
29	0.485
31	0.515
33	0.545
35	0.574
37	0.602
39	0.629
41	0.656
43	0.682
45	0.707
47	0.731
49	0.755
51	0.777
53	0.799
55	0.819
57	0.839
59	0.857
61	0.875
63	0.891
65	0.906
67	0.921
69	0.934
71	0.946
73	0.956
75	0.966
77	0.974
79	0.982
81	0.988
83	0.993
85	0.996
87	0.999
89	1.000

Angle	Sin Θ
1.5	0.026
3.5	0.061
5.5	0.096
7.5	0.131
9.5	0.165
11.5	0.199
13.5	0.233
15.5	0.267
17.5	0.301
19.5	0.334
21.5	0.367
23.5	0.399
25.5	0.431
27.5	0.462
29.5	0.492
31.5	0.522
33.5	0.552
35.5	0.581
37.5	0.609
39.5	0.636
41.5	0.663
43.5	0.688
45.5	0.713
47.5	0.737
49.5	0.760
51.5	0.783
53.5	0.804
55.5	0.824
57.5	0.843
59.5	0.862
61.5	0.879
63.5	0.895
65.5	0.910
67.5	0.924
69.5	0.937
71.5	0.948
73.5	0.959
75.5	0.968
77.5	0.976
79.5	0.983
81.5	0.989
83.5	0.994
85.5	0.997
87.5	0.999
89.5	1.000