SUBCOURSE MM 0483 **EDITION** 0

US ARMY MISSILE AND MUNITIONS CENTER AND SCHOOL

THERMOMETRY

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM

THERMOMETRY

TABLE OF CONTENTS

GENERAL INFORMATION

This subcourse consists of two lessons and an examination. Each of the lessons is divided into two parts; the text and the lesson exercises. A heading at the beginning of each lesson gives the title, the hours of credit, and the objectives of the lesson. The final examination consists of questions covering the entire subcourse.

If a change sheet is included, be sure to post the changes before starting the subcourse.

THE TEXT

All the text material required for this subcourse is provided in the packet. The text is the information you must study. Read this very carefully. You may keep the text.

THE LESSON OBJECTIVE

Following the text of each lesson are the lesson exercises. After you have studied the text of each lesson, answer the lesson exercises. After you have answered all the questions, go back to the text and check your answers. Remember your answers should be based on what is in the text and not on your own experience or opinions. If there is a conflict, use the text in answering the question.

When you are satisfied with your answers, check them against the approved solution in back of this text. Re-study those areas where you have given an incorrect answer by checking the reference given after each answer.

CORRESPONDENCE COURSE
OF THE
U.S. ARMY MISSILE AND MUNITIONS
CENTER AND SCHOOL

ACCP SUBCOURSE NUMBER MM 0483, THERMOMETRY
(4 Credit Hours)

INTRODUCTION

Everyone is concerned with the effects of temperature. It affects your comfort and discomfort; the temperature of your body is directly related to your health. In the technical field we are also concerned with temperature. High temperature may cause equipment to overheat or burn out, while low temperature may prevent equipment from reaching optimum operating temperature, thereby reducing efficiency. As our technology advances, temperature becomes even more important. The success or failure of an astronaut's voyage into space, or even his life, can be jeopardized by extreme temperature.

Since temperature affects all factors of our daily lives, it is essential that we be able to accurately determine temperatures. We use various types of thermometers to do this and these thermometers must be accurate. We know that under controlled conditions, certain events occur in nature at definite points on the heat scale. By agreement among the member Nation of the International Conference of Weights and Measurements, these points have been assigned definite temperatures. Based on the occurrences of these natural events and international agreements, we can calibrate and/or compare thermometers to determine their accuracy. As calibration specialists, you will be required to determine the accuracy of various thermometers.

The importance of temperature measurement cannot be overemphasized. Your value to your unit will be enhanced significantly through the increased versatility you develop from this subcourse.

This subcourse is organized as follows:

Lesson 1 Introduction to Thermometry............................ 1 Hour

Lesson 2 Calibration and Use of Standards........................ 2 Hours

Examination.. 1 Hour

ACKNOWLEDGEMENTS

This subcourse was adapted for Army use from the following:

Manual for Model RCSI-SP Ice-Point Calibration Standard, Joseph Kaye & Company, Inc.

Equiphase Triple Point of Water Cell, Trans-Sonics, Inc.

TB 9-4931-428-50

TB 9-6685-314-50

Constant Temperature Baths, Hallikianen Instruments

SOLDIER TASKS

This subcourse supports the following tasks from Soldier Manual, FM 9-35H1/2.

093-435-1290 Calibrate Thermometer, Model MIL-T-12625

093-435-3297 Calibrate Electronic Ice Point Standard, Model PCS1-SP

093-435-3300 Calibrate Thermometer Set, Model 9710479

LESSON 1. INTRODUCTION TO THERMOMETRY

ACCP Subcourse Number MM 0483........ Thermometry

Lesson Objectives.................................. After reading this lesson you should have a basic knowledge of the development of various thermometers and their use, and be able to answer all review questions correctly pertaining to:

A. Thermometers

1. Air
2. Mercury
3. Bimetalic (Helix)
4. Thermocouple
5. B. Temperature conversion Resistance
1. Celsius
2. Fahrenheit
3. Kelvin
4. Rankine

Credit Hours... One hour

TEXT

1. GENERAL

Temperature. How hot is hot? Don't try to answer this question now; it will probably drive you crazy---- and we want you to be sane while studying this subcourse. Although we can't tell you how hot is hot, we do know we can measure the "hotness" of an object by determining its temperature. Temperature means intensity of heat. In other words, temperature may be defined as-- the condition of a body which determines the transfer of heat to or from other bodies. If you prefer a more technical definition--the absolute temperature of a body is proportional to the average kinetic energy of the molecules of which the body is composed. Now, before we get too confusing----what is actually measured when the temperature of an object is determined?
Basically, temperature means intensity of heat, and may be defined as an arbitrary scale. Temperature is only relative and is difficult to define in terms of simplest concepts.

2. There are many temperature measuring devices. One such device is the Air Thermometer. Galileo is credited with the development of an air thermometer in 1593.

Although his thermometer has been improved upon, it is still not used for accurate measurements. Basically, the air thermometer is a glass tube with an opening at one end and a bulb at the other end. The open end is submerged in a dish of water.

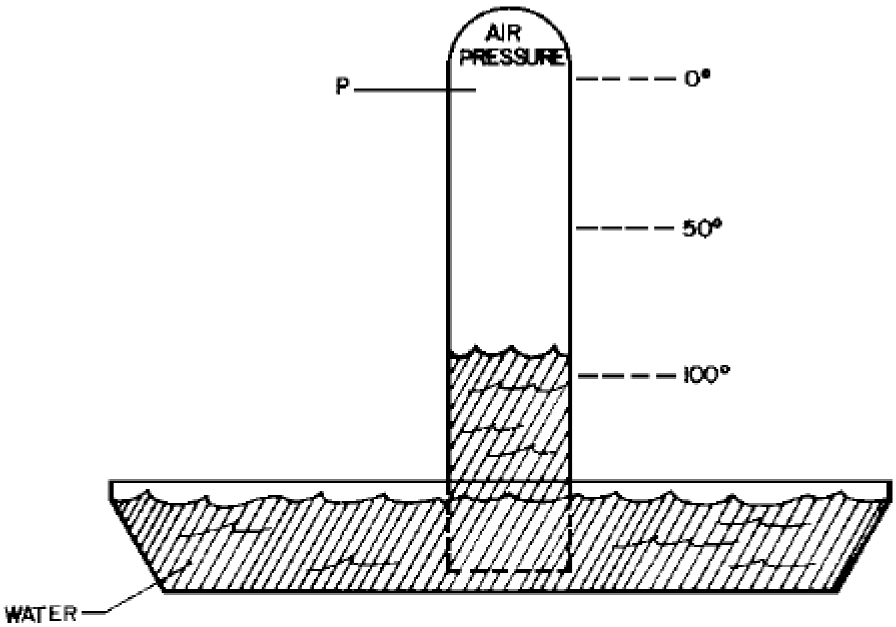


Figure 1. Air Thermometer.

The air trapped in the bulb expands as the ambient (surrounding) temperature increases, thus the increased air pressure (P) forces some water out of the tube. The water level of the tube is related to a scale giving an arbitrary indication of temperature. Detrimental to the accuracy of the air thermometer are changes in atmospheric pressure which vary the water level. Also detrimental is the fact that water evaporates.

The useful range of this instrument is limited, as it operates between the freezing and boiling points of water.

It is apparent from the description of the air thermometer, that a more accurate and dependable means of determining temperature was needed.

3. CLOSED-GLASS LIQUID THERMOMETERS.

Leopoldo, Cardinal de Medici made the first closed-glass liquid thermometers, around 1654. These thermometers, widely used in France and England, were graduated into 50, 100, or 300 degrees. They were roughly standardized by the heat of the sun and the cold of ice water, and filled with distilled colored wine. The advantage of a liquid like wine was that its expansion was independent of air pressure. Mercury and water thermometers were also tried by the Florentines but abandoned because there expansion was too small. Later this problem was overcome by making thermometers with finer bores, thereby increasing their sensitivity, and by the middle of the 18th century mercury thermometers had superseded others because of their near uniform expansion, low freezing point and high boiling point. The mercury thermometer consists of a narrow glass tube (called a capillary) with a bulb blown on one end to act as a reservoir for mercury. The other end of the tube is sealed after all the air is evacuated (refer to figure 2).

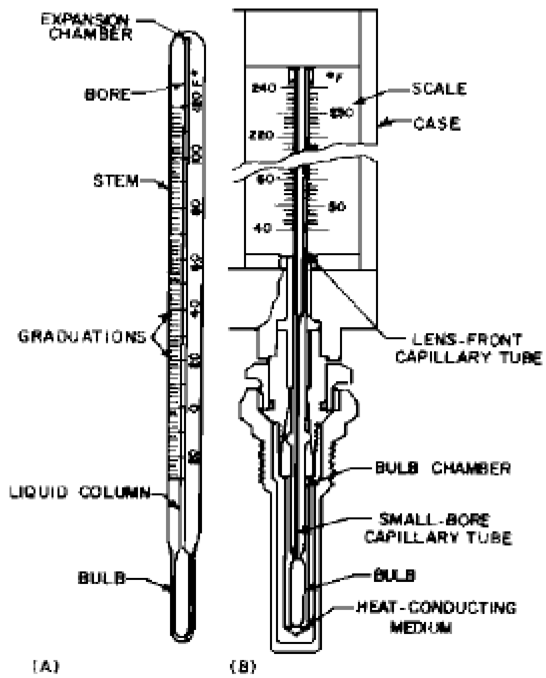


Figure 2. Liquid-in-glass Thermometer. (a) Etched-stem clinical thermometer. (b) Graduated-scale industrial themometer.

Sensitivity to a rising temperature causes both the glass and mercury to expand. However, the mercury expands more than the glass, forcing mercury up the capillary. As you observe the mercury column, it is very practical to etch the temperature scale on the glass tube. You no doubt have had your body temperature taken with a medical (mercury) thermometer. If you were observant you should have noticed that the nurse shook the thermometer. This was done to force the mercury down into the bulb so that an accurate measurement could be made. The mercury in some thermometers will separate. A thermometer in this condition can not be used. The mercury must be re-combined. One way of doing this is to heat the thermometer causing the mercury to expand up the capillary tube and re-combine with any mercury that has separated. If the mercury will not re-combine you must not use the thermometer. It is quite obvious that when the mercury expands it has only one place to go (up the capillary tube).
The rate at which the mercury column rises is dependent on temperature change, but it is also controlled by the diameter of the capillary tube. The accuracy of the mercury thermometer depends on the uniformity of the glass reservoir and capillary tube. Calibration of the temperature scale is also important.
The accuracy of the mercury thermometer is also dependent on the purity of the mercury. If impurities are in the mercury, the expansion rate could be affected and the resultant nonlinearity would produce erroneous readings.
NOTE: Do not confuse the mercury thermometer with the so-called thermometers you find in 5 and 10 cent stores that contain red dye in an alcohol base.
4. IMMERSION SET.
Just as the freezing and boiling points of water restrict the range of the air thermometer, mercury, which freezes at -38.87˚¸C (Celsius) and boils at 356.58˚¸C limits the range of the mercury thermometer. The glass tubing is not critical as it melts a 500˚¸C to 800˚¸C.

The most accurate glass thermometers we have at the secondary transfer level are in the total immersion set. This set has a combined range of -10˚¸C to 360˚¸C with an accuracy of 0.2˚¸C. The total immersion set is classified as a secondary reference standard.
How can the immersion set indicate up to 360˚¸C when mercury boils at 357˚¸C? Standard thermometers which indicate over 150˚¸C contain mercury and an inert gas rather than a vacuum. Expanding mercury compresses the gas; this is very important, for near the boiling point of mercury, the gas pressure keeps the mercury from vaporizing. The thermometers we use contain nitrogen gas.
5. BIMETALLIC THERMOMETERS.
Bimetallic and mercury thermometers operate on the same basic principle; that is, they operate on the principle of different expansion rates of materials.
In bimetallic thermometers, usually, two types of nickel alloys are used: one for its thermal characteristics and the other one for a reference.
One of the most common reference alloys is called Invar because, at normal atmospheric temperature, its length is invariable (it neither expands nor contracts). Of course, what we really mean is that the expansion rate is negligible.
When a straight bimetallic strip fastened at one end is heated, it bends to form an arc or a circle. This bending action or curvature, by a mechanically suitable system and scale, can be used to move a pointer tip so that it describes an arc. (Figure 3)

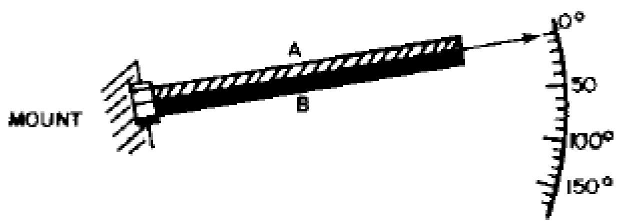


Figure 3. Bimetallic thermometer.

Obviously, as temperature is increased, the bimetallic strip must bend downward because the top layer would expand at a greater rate than the base metal. (Figure 4)

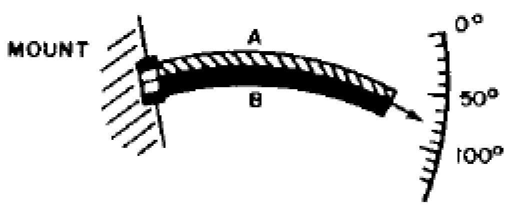


Figure 4. Bimetallic thermometer (true deflection).

If metal B had the higher coefficient of expansion, it would expand at a greater rate and cause the pointer to move upward. (Figure 5).

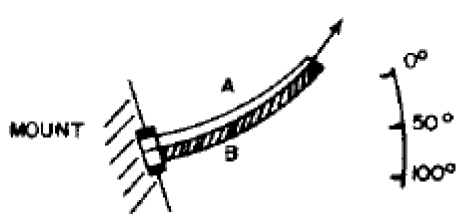


Figure 5. Bimetallic thermometer (false deflection).

When a substance is subjected to temperature changes, it will either expand or contract. Thus, the actual size depends to some extent on the reaction of material to heat.
The amount of expansion or contraction is related to the change in temperature and can be considered a linear function; that is, the amount of expansion can be considered as some fixed rate per degree of temperature change. Each material has its characteristic (coefficient of expansion) rate.
A positive coefficient means that the substance expands as the temperature rises. A negative coefficient indicates that the substance contracts as the temperature rises.
Alloys with widely different coefficients of expansion are welded together for small thermal scale ranges such as 0˚¸ to 100˚¸C. Alloys with smaller differences of expansion are used for larger scale ranges in the range of -100˚¸ to 1,000˚¸C.
6. BIMETALLIC (HELIX) THERMOMETER

There are many versions of the bimetallic thermometer. Another type, which is quite common, consists of a bimetallic coil (helix) encased in a tube with an indicator and scale at the top.
In this type the twisting action of the coil causes the long shaft to rotate the pointer. The thermal element at the bottom of the shaft is the only portion of the thermometer sensitive to temperature changes.
The bimetallic thermometers, though some of them are very good, are not accurate enough to be considered as standards. However, they are rugged, inexpensive, and easy to read (see figure 6).

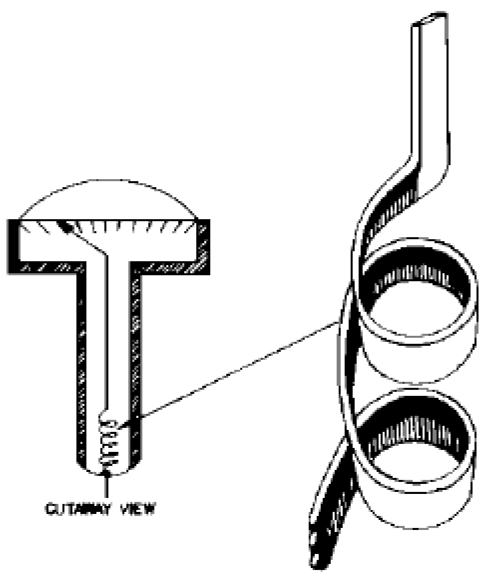


Figure 6. Bimetallic (helix) thermometer.

Even though the bimetallic thermometer is not accurate enough to be considered a standard, it would have to be used for temperature measurements in the range of 400˚¸C, if the only other choice is a mercury thermometer. The total immersion set is useful only to 360˚¸C.
There are other thermometers for high-temperature use such as optical pyrometers. These are used largely for checking molten metal by the color of the melt. They only give

relative indications. Since we are interested in accurate temperature measurement, these types of thermometers will not be discussed.

The thermometers discussed thus far can be considered as mechanical in operation. Now we will see how electrical thermometers operate.

7. THERMOCOUPLE THERMOMETER

The principle of the thermocouple is based on a law of thermodynamics which states, "A thermal electromotive force (EMF) is developed (and can be measured) when the junctions of any two dissimilar metals are at different temperatures."

From the previous statement, it can be noted that a junction formed by two dissimilar metals, when heated, will produce an electric current. Also, there will be other junctions formed by connecting leads to an ammeter circuit. (See figure 7.)

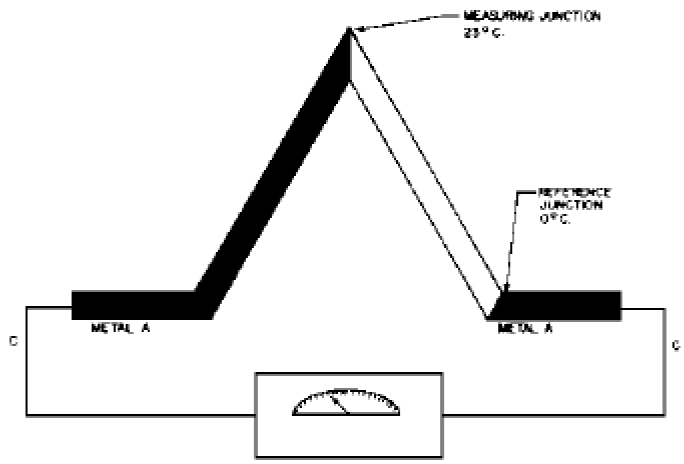


Figure 7. Basic thermocouple circuit.

There definitely must be a thermal difference between the junctions of any two dissimilar metals that are at different temperatures.

The voltage generated by the thermocouple is proportional to the temperature difference between measuring and reference junctions.

Although the thermocouple is useful over a wide range of temperatures, there are two basic limitations to its range. First, the reaction of thermocouples near the reference temperature and, then, the reaction of the "couples" at high temperature.

Thermocouple sensitivity decreases as the difference between the measured temperature and the reference temperature becomes very small. The apparent loss of sensitivity is due to the amplitude of the voltage being generated for small differences of temperature. At high temperatures, thermocouples are subject to melting action which will damage, if not destroy, them.

At temperatures very close to the reference temperature, thermocouples generate very small thermal voltages; a condition which results in poor sensitivity. To overcome this situation, more sensitive meter circuits are used or the thermocouples are mounted in series (called a thermopile) to increase the voltage output.

At high temperature the "couples" are subject to melting action. The answer to this problem is to use an indirect measuring technique or materials with higher melting points.

Thermocouples are used to measure temperature in the range of -200˚¸C to 2,000˚¸C. This of course is a general statement; the actual range varies with the type of "couple" used.

ELECTRICAL RESISTANCE THERMOMETER

Another type of electrical thermometer is the resistance thermometer. It operates on the principle that resistance varies as a function of heat.

If the resistance increases as temperature increases, the resistance is said to have a positive temperature coefficient. If the resistance decreases as temperature increases, it is said to have a negative coefficient.

The resistance thermometer in its simplest form is a series circuit consisting of a battery, thermal resistance, ammeter, and current limiting resistor. (Refer to figure 8)

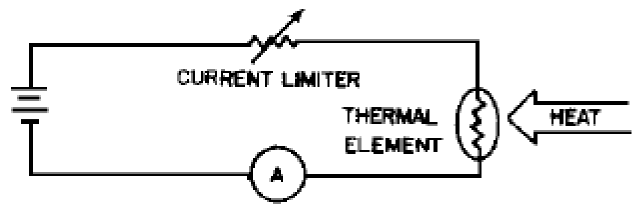


Figure 8. Simplified resistance thermometer.

The current limiting resistor serves a dual role. First, as a calibration adjustment for the meter and second, as current limiter to increase the useful life of the battery.

When heat is applied to a thermal element having a positive temperature coefficient, the meter would actually indicate less current flow, but the scale face would indicate a higher temperature level. Full scale temperature reading would occur when the thermal resistance becomes large enough to cause the meter to reach the "zero" current level (arbitrary minimum deflection level).

You have read about quite a few thermometers thus far in this subcourse. There are others, but the ones already explained convey the theory that is necessary at this time.

8. TEMPERATURE SCALES.

Thus far, reference has been made to temperature on what is called the Celsius scale. We will now discuss the various scales in common use so that they will be more meaningful. People who attempted to measure temperature a few centuries ago had a hard time trying to develop a scale. They did come up with some rather unique systems. For instance, in 1701, Sir Issac Newton developed a scale based on the freezing point of water (0) and body temperature (12). In 1714, Gabriel Fahrenheit marked a mercury thermometer with zero as a point in an ice-salt bath and 12 as blood temperature (I wonder how they measured that?). There were many other standards such as: temperature of a deep cave, the coldest day, etc..... It is easy to see how such references are ridiculous from our point of view. Imagine calibrating thermometers only on the coldest day of the year.

A man named Celsius produced a scale where 0˚¸ is the freezing point (ice point) of water and 100˚¸ the steam point of boiling water. It is divided into 100 equal parts and is called the Celsius or centigrade (100 gradient) scale. The Celsius scale is used internationally for precision laboratory measurements. The symbol ˚¸C indicates degree Celsius or centigrade. However, Celsius is the preferred designation.

In 1858, Lord Kelvin conceived a new scale which started at -273˚¸C. It was based on the assumption that all molecular motion ceased at this particular temperature (-273˚¸C). This reference is called absolute zero. His scale starts at absolute zero and reads upward in degrees Kelvin. Each Kelvin degree is equivalent to a Celsius degree. Actually 0˚¸K is -273.16˚¸C, but for general measurements the value -273˚¸C is used. The advantage of the Kelvin scale is that all temperatures are positive with respect to absolute zero.

Now lets try to convert from one temperature scale to another. What would a Celsius scale read if a Kelvin scale measuring the same temperature indicates 273˚¸?

If your answer is 0˚¸ Celsius is equivalent to 273˚¸ Kelvin I warmly agree with you Subtracting 273 from a Kelvin scale value will result in the equivalent Celsius scale value.

273˚¸K minus 273 = 0˚¸C.

A picture is worth a thousand words. Now, notice the relationship between the Kelvin and Celsius (centigrade) scales.

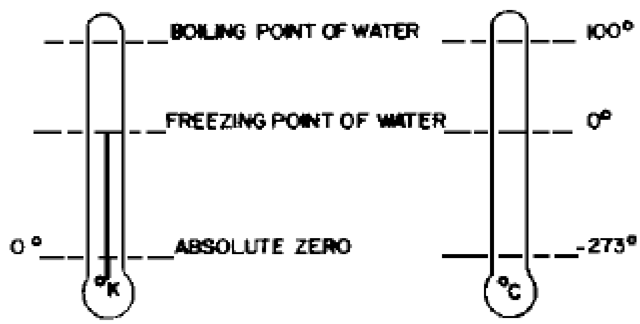


Figure 9. Kelvin-Celsius relationship.

Remember! To convert from ˚¸K to ˚¸C subtract 273 from the Kelvin reading.

Example: 200˚¸K minus 273˚¸ = -73˚¸C.

Lets try another problem. What temperature on the Kelvin scale would be equivalent to the steam point of water?

There are two ways of obtaining the answer:

1. To convert N degrees Kelvin to degrees Celsius, subtract 273˚¸K from N degrees Kelvin.
2. Knowing the steam point of water is 100˚¸C, add 273 to find the temperature above absolute zero. For example, 100˚¸C, + 273 = 373˚¸C.

What is -40˚¸C in terms of the Kelvin scale? It is easy to convert between degrees Kelvin and degrees Celsius. Since ˚¸K = ˚¸C + 273, we have ˚¸K = -40 + 273, hence K = 233˚¸.

As pointed out before, the Kelvin scale readings are all positive in respect to absolute zero. The Kelvin scale is used frequently in scientific work, especially in the (-)˚¸C region.

There are two other temperature scales worth discussing, because they are in common use throughout the English speaking countries.

9. FAHRENHEIT SCALE.

Thermometers used for everyday household use are calibrated in degrees (F) Fahrenheit. The Fahrenheit scale divides the difference between the ice point and steam point of water into 180 increments.

Compare 180˚¸F to 100˚¸C, between the same reference points, and you will notice a 9/5 relationship. Another relationship is that 32˚¸F is equivalent to 0 C, while the steam point of water is 212˚¸F. (Refer to figure 10)

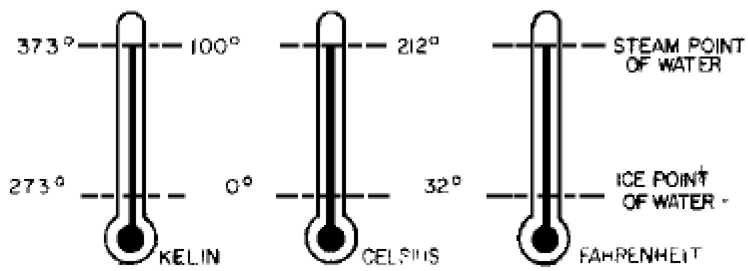


Figure 10. Temperature scale relationships.

From the relationship between ˚¸C and ˚¸F, the following formulas are derived: ˚¸F = 9 (˚¸C) + 32 ˚¸C = 5 (˚¸F - 32) - - 5 9

Using the appropriate formula, what temperature on the Fahrenheit scale would be equivalent to +40˚¸C?

If you answer is 104˚¸ F you are correct. Plugging values into a formula isn't too hard. Example: 9/5 X 40 +32 is equal to 104˚¸F.

Now try this one. What temperature on the Celsius scale is equivalent to a -40˚¸F?

What about that! You are right, if your answer is -40˚¸. ˚¸C = 5 (-40-32) = 5 (-72) = 5 X (-8) = -40. C = -40˚¸. - - 9 9

There is only one point on the Celsius and Fahreheit scales that is identical in value and temperature, the -40˚¸ point. Quite often in scientific work, -40˚¸ is used where the scale is not stated because this fact is understood.

Let's try one more conversion. What temperature on the Fahrenheit scale would be equivalent to absolute zero? Your answer: -459˚¸F. Very Good! If -273˚¸ C is absolute zero, ˚¸F = 9/5 (-273) + 32˚¸F = -459.4. Actually -460 is closer, due to the error in the factor 273 being rounded off to three digits. The answer to the problem is an important point which will be discussed.

10. RANKINE SCALE

Just as the Kelvin and Celsius scales are related, the Rankine scale is related to the Fahrenheit scale.

The Rankine scale, which is used in the United States by engineers, starts at absolute zero and reads up in Fahrenheit increments. Referring to figure 9, you will see the number 492 on the Rankine (R') scale. If you subtract 32 from 492 you will have the number 460 which we previously found. Since the Rankine scale starts at absolute zero all temperature indications are positive values

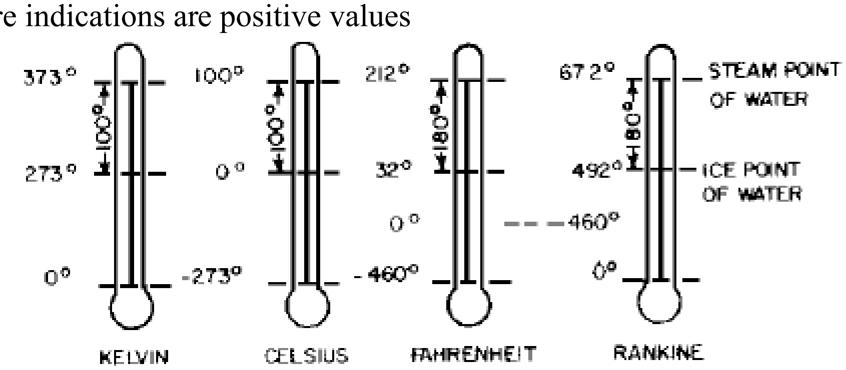


Figure 11. Important temperature relationships.

To convert ˚¸R' to ˚¸F subtract 460 from ˚¸R' and your answer is in ˚¸F.

What is -40 ˚¸F on the Rankine scale Solution ˚¸R' = -40˚¸F + 460 ˚¸R' = 420
Now, convert 230˚¸K to a Rankine scale equivalent.
YOUR ANSWER: 414˚¸R'.
You're on the ball...considering there is a 9/5 relationship per degree F and C. The same condition holds true for the Rankine and Kelvin scales. Hence, it is very easy to compare temperatures on the ˚¸R' and ˚¸K scales.

Example: $230^{o}\ K \times \frac{9}{5} = {}^{o}\ R'$

$414 = \ R'$

TEMPERATURE SCALE RELATIONSHIPS

Let us briefly summarize some of the basic relationships between temperature scales.
1 C degree is equivalent to 1 K degree.
1 F degree is equivalent to 1 R' degree.
1 C degree is equivalent to 9/5 F degrees.
1 K degree is equivalent to 9/5 R' degrees.
273˚¸ K is equivalent to 0˚¸C.
460 R' is equivalent to 0˚¸F.
Also, the two formulas for Celsius--Fahrenheit conversion are good toknow.

$$^{o}F = \frac{9}{5}(^{o}C) + 32$$

$$^{o}C = 5\ (^{o} - 32)$$

$$^{o}C = \frac{5}{9}(^{o}$$

CONVERSION CHART

Another shortcut in working with temperature scales can be made by use of conversion charts. Please refer to the chart on the following page.
At the top of the chart there is a very important note (please read it).
Now, solve the following problems by using the chart. Write your answers in the space provided.
1. 10˚¸C to ˚¸F. ________________________
2. -170˚¸C to ˚¸F. ________________________
3. 1,832˚¸F to ˚¸C. ________________________
4. 1,060˚¸C to ˚¸F. ________________________
Check your answers with the solutions on page 16.

TEMPERATURE CONVERSION CHART

THE numbers in bold face type refer to the temperature either in degrees Centigrade or Fahrenheit which it is desired to convert into the other scale. If converting from Fahrenheit degrees to Centigrade degrees, the equivalent will be found in the left column, while if converting from degrees Centigrade to degrees Fahrenheit, the answer will be found in the column on the right.

INTERPOLATION FACTORS

C.		F.	C.		F.
0.56	**1**	1.8	3.33	**6**	10.8
1.11	**2**	3.6	3.89	**7**	12.6
1.67	**3**	5.4	4.44	**8**	14.4
2.22	**4**	7.2	5.00	**9**	16.2
2.78	**5**	9.0	5.56	**10**	18.0

—459.4 to 25

C.		F.
—273	**—459.4**	
—268	**—450**	
—262	**—440**	
—257	**—430**	
—251	**—420**	
—246	**—410**	
—240	**—400**	
—234	**—390**	
—229	**—380**	
—223	**—370**	
—218	**—360**	
—212	**—350**	
—207	**—340**	
—[illegible]	**—330**	
—196	**—320**	
—190	**—310**	
—184	**—300**	
—179	**—290**	
—173	**—280**	
—169	**—273**	—459.4
—168	**—270**	—454
—162	**—260**	—436
—157	**—250**	—418
—151	**—240**	—400
—146	**—230**	—382
—140	**—220**	—364
—134	**—210**	—346
—129	**—200**	—328
—123	**—190**	—310
—118	**—180**	—292
—112	**—170**	—274
—107	**—160**	—256
—101	**—150**	—238
— 95.6	**—140**	—220
— 90.0	**—130**	—202
— 84.4	**—120**	—184
— 78.9	**—110**	—166
— 73.3	**—100**	—148
— 67.8	**— 90**	—130
— 62.2	**— 80**	—112
— 56.7	**— 70**	— 94
— 51.1	**— 60**	— 76
— 45.6	**— 50**	— 58
— 40.0	**— 40**	— 40
— 34.4	**— 30**	— 22
— 28.9	**— 20**	— 4
— 23.3	**— 10**	14
— 17.8	**0**	32
— 17.2	**1**	33.8
— 16.7	**2**	35.6
— 16.1	**3**	37.4
— 15.6	**4**	39.2
— 15.0	**5**	41.0
— 14.4	**6**	42.8
— 13.9	**7**	44.6
— 13.3	**8**	46.4
— 12.8	**9**	48.2
— 12.2	**10**	50.0
— 11.7	**11**	51.8
— 11.1	**12**	53.6
— 10.6	**13**	55.4
— 10.0	**14**	57.2
— 9.44	**15**	59.0
— 8.89	**16**	60.8
— 8.33	**17**	62.6
— 7.78	**18**	64.4
— 7.22	**19**	66.2
— 6.67	**20**	68.0
— 6.11	**21**	69.8
— 5.56	**22**	71.6
— 5.00	**23**	73.4
— 4.44	**24**	75.2
— 3.89	**25**	77.0

25 to 100

C.		F.
— 3.89	**25**	77.0
— 3.33	**26**	78.8
— 2.78	**27**	80.6
— 2.22	**28**	82.4
— 1.67	**29**	84.2
— 1.11	**30**	86.0
— 0.56	**31**	87.8
0	**32**	89.6
0.56	**33**	91.4
1.11	**34**	93.2
1.67	**35**	95.0
2.22	**36**	96.8
2.78	**37**	98.6
3.33	**38**	100.4
3.89	**39**	102.2
4.44	**40**	104.0
5.00	**41**	105.8
5.56	**42**	107.6
6.11	**43**	109.4
6.67	**44**	111.2
7.22	**45**	113.0
7.78	**46**	114.8
8.33	**47**	116.6
8.89	**48**	118.4
9.44	**49**	120.2
10.0	**50**	122.0
10.6	**51**	123.8
11.1	**52**	125.6
11.7	**53**	127.4
12.2	**54**	129.2
12.8	**55**	131.0
13.3	**56**	132.8
13.9	**57**	134.6
14.4	**58**	136.4
15.0	**59**	138.2
15.6	**60**	140.0
16.1	**61**	141.8
16.7	**62**	143.6
17.2	**63**	145.4
17.8	**64**	147.2
18.3	**65**	149.0
18.9	**66**	150.8
19.4	**67**	152.6
20.0	**68**	154.4
20.6	**69**	156.2
21.1	**70**	158.0
21.7	**71**	159.8
22.2	**72**	161.6
22.8	**73**	163.4
23.3	**74**	165.2
23.9	**75**	167.0
24.4	**76**	168.8
25.0	**77**	170.6
25.6	**78**	172.4
26.1	**79**	174.2
26.7	**80**	176.0
27.2	**81**	177.8
27.8	**82**	179.6
28.3	**83**	181.4
28.9	**84**	183.2
29.4	**85**	185.0
30.0	**86**	186.8
30.6	**87**	188.6
31.1	**88**	190.4
31.7	**89**	192.2
32.2	**90**	194.0
32.8	**91**	195.8
33.3	**92**	197.6
33.9	**93**	199.4
34.4	**94**	201.2
35.0	**95**	203.0
35.6	**96**	204.8
36.1	**97**	206.6
36.7	**98**	208.4
37.2	**99**	210.2
37.8	**100**	212.0

100 to 800

C.		F.
38	**100**	212
43	**110**	230
49	**120**	248
54	**130**	266
60	**140**	284
66	**150**	302
71	**160**	320
77	**170**	338
82	**180**	356
88	**190**	374
93	**200**	392
99	**210**	410
100	**212**	413
104	**220**	428
110	**230**	446
116	**240**	464
121	**250**	482
127	**260**	500
132	**270**	518
138	**280**	536
143	**290**	554
149	**300**	572
154	**310**	590
160	**320**	608
166	**330**	626
171	**340**	644
177	**350**	662
182	**360**	680
188	**370**	698
193	**380**	716
199	**390**	734
204	**400**	752
210	**410**	770
216	**420**	788
221	**430**	806
227	**440**	824
232	**450**	842
238	**460**	860
243	**470**	878
249	**480**	896
254	**490**	914
260	**500**	932
266	**510**	950
271	**520**	968
277	**530**	986
282	**540**	1004
288	**550**	1022
293	**560**	1040
299	**570**	1058
304	**580**	1076
310	**590**	1094
316	**600**	1112
321	**610**	1130
327	**620**	1148
332	**630**	1166
338	**640**	1184
343	**650**	1202
349	**660**	1220
354	**670**	1238
360	**680**	1256
366	**690**	1274
371	**700**	1292
377	**710**	1310
382	**720**	1328
388	**730**	1346
393	**740**	1364
399	**750**	1382
404	**760**	1400
410	**770**	1418
416	**780**	1436
421	**790**	1454
427	**800**	1472

800 to 1500

C.		F.
427	**800**	1472
432	**810**	1490
438	**820**	1508
443	**830**	1526
449	**840**	1544
454	**850**	1562
460	**860**	1580
466	**870**	1598
471	**880**	1616
477	**890**	1634
482	**900**	1652
488	**910**	1670
493	**920**	1688
499	**930**	1706
504	**940**	1724
510	**950**	1742
516	**960**	1760
521	**970**	1778
527	**980**	1796
532	**990**	1814
538	**1000**	1832
543	**1010**	1850
549	**1020**	1868
554	**1030**	1886
560	**1040**	1904
566	**1050**	1922
571	**1060**	1940
577	**1070**	1958
582	**1080**	1976
588	**1090**	1994
593	**1100**	2012
599	**1110**	2030
604	**1120**	2048
610	**1130**	2066
616	**1140**	2084
621	**1150**	2102
627	**1160**	2120
632	**1170**	2138
638	**1180**	2156
643	**1190**	2174
649	**1200**	2192
654	**1210**	2210
660	**1220**	2228
666	**1230**	2246
671	**1240**	2264
677	**1250**	2282
682	**1260**	2300
688	**1270**	2318
693	**1280**	2336
699	**1290**	2354
704	**1300**	2372
710	**1310**	2390
716	**1320**	2408
721	**1330**	2426
727	**1340**	2444
732	**1350**	2462
738	**1360**	2480
743	**1370**	2498
749	**1380**	2516
754	**1390**	2534
760	**1400**	2552
766	**1410**	2570
771	**1420**	2588
777	**1430**	2606
782	**1440**	2624
788	**1450**	2642
793	**1460**	2660
799	**1470**	2678
804	**1480**	2696
810	**1490**	2714
816	**1500**	2732

1500 to 2000

C.		F.
816	**1500**	2732
821	**1510**	2750
827	**1520**	2768
832	**1530**	2786
838	**1540**	2804
843	**1550**	2822
849	**1560**	2840
854	**1570**	2858
860	**1580**	2876
866	**1590**	2894
871	**1600**	2912
877	**1610**	2930
882	**1620**	2948
888	**1630**	2966
893	**1640**	2984
899	**1650**	3002
904	**1660**	3020
910	**1670**	3038
916	**1680**	3056
921	**1690**	3074
927	**1700**	3092
932	**1710**	3110
938	**1720**	3128
943	**1730**	3146
949	**1740**	3164
954	**1750**	3182
960	**1760**	3200
966	**1770**	3218
971	**1780**	3236
977	**1790**	3254
982	**1800**	3272
988	**1810**	3290
993	**1820**	3308
999	**1830**	3326
1004	**1840**	3344
1010	**1850**	3362
1016	**1860**	3380
1021	**1870**	3398
1027	**1880**	3416
1032	**1890**	3434
1038	**1900**	3452
1043	**1910**	3470
1049	**1920**	3488
1054	**1930**	3506
1060	**1940**	3524
1066	**1950**	3542
1071	**1960**	3560
1077	**1970**	3578
1082	**1980**	3596
1088	**1990**	3614
1093	**2000**	3632

2000 to 2500

C.		F.
1093	**2000**	3632
1099	**2010**	3650
1104	**2020**	3668
1110	**2030**	3686
1116	**2040**	3704
1121	**2050**	3722
1127	**2060**	3740
1132	**2070**	3758
1138	**2080**	3776
1143	**2090**	3794
1149	**2100**	3812
1154	**2110**	3830
1160	**2120**	3848
1166	**2130**	3866
1171	**2140**	3884
1177	**2150**	3902
1182	**2160**	3920
1188	**2170**	3938
1193	**2180**	3956
1199	**2190**	3974
1204	**2200**	3992
1210	**2210**	4010
1216	**2220**	4028
1221	**2230**	4046
1227	**2240**	4064
1232	**2250**	4082
1238	**2260**	4100
1243	**2270**	4118
1249	**2280**	4136
1254	**2290**	4154
1260	**2300**	4172
1266	**2310**	4190
1271	**2320**	4208
1277	**2330**	4226
1282	**2340**	4244
1288	**2350**	4262
1293	**2360**	4280
1299	**2370**	4298
1304	**2380**	4316
1310	**2390**	4334
1316	**2400**	4352
1321	**2410**	4370
1327	**2420**	4388
1332	**2430**	4406
1338	**2440**	4424
1343	**2450**	4442
1349	**2460**	4460
1354	**2470**	4478
1360	**2480**	4496
1366	**2490**	4514
1371	**2500**	4532

2500 to 3000

C.		F.
1371	**2500**	4532
1377	**2510**	4550
1382	**2520**	4568
1388	**2530**	4586
1393	**2540**	4604
1399	**2550**	4622
1404	**2560**	4640
1410	**2570**	4658
1416	**2580**	4676
1421	**2590**	4694
1427	**2600**	4712
1432	**2610**	4730
1438	**2620**	4748
1443	**2630**	4766
1449	**2640**	4784
1454	**2650**	4802
1460	**2660**	4820
1466	**2670**	4838
1471	**2680**	4856
1477	**2690**	4874
1482	**2700**	4892
1488	**2710**	4910
1493	**2720**	4928
1499	**2730**	4946
1504	**2740**	4964
1510	**2750**	4982
1516	**2760**	5000
1521	**2770**	5018
1527	**2780**	5036
1532	**2790**	5054
1538	**2800**	5072
1543	**2810**	5090
1549	**2820**	5108
1554	**2830**	5126
1560	**2840**	5144
1566	**2850**	5162
1571	**2860**	5180
1577	**2870**	5198
1582	**2880**	5216
1588	**2890**	5234
1593	**2900**	5252
1599	**2910**	5270
1604	**2920**	5288
1610	**2930**	5306
1616	**2940**	5324
1621	**2950**	5342
1627	**2960**	5360
1632	**2970**	5378
1638	**2980**	5396
1643	**2990**	5414
1649	**3000**	5432

Answers to problems (using the temperature conversion chart).

1. 50˚,F
2. -274˚,F
3. 1,000˚,C
4. 1,940˚,F

11. CONCLUSION.

It is evident that there is much more material to be discussed. We have in this lesson just scratched the surface. There are many types of thermometers; each has it place. You should have a good mental picture of the air, mercury, bimetallic, thermocouple and platinum resistance thermometers.

It is also important to understand what is meant by such terms as ° K, °R, °C, and °F, the interrelations of these scales and how they are used should also be known.

In the succeeding lesson you will have ample discussion on the principles and use of calibration standards. Now answer questions 1 thru 10.

EXERCISES FOR LESSON 1

1. What is meant by "intensity of heat"?

A. temperature
B. transfer of heat
C. molecular energy
D. the lack of cold

2. In which direction, does the column of water flow in an air thermometer when the ambient temperature increases?

A. up
B. does not move
C. down
D. expands to the side only

3. What is the range of the total immersion set?

A. -0C - 1,500 C
B. -0C - 360 C
C. -10C - 360 C
D. -0C - 380 C

4. What is used to increase the range of mercury thermometers?

A. mercury of a higher density
B. mercury that has impurities added
C. an inert gas
D. a higher vacuum

5. What is meant by a negative coefficient of expansion?

A. substance expands as temperature rises
B. substance contracts as temperature rises
C. substance stays the same as temperature rises
D. the expansion or contraction of a substance is independent of temperature

6. What conditions are required to develop a thermal EMF in a thermocouple?

A. reference junctions must be within 20 to one another
B. the junctions of two dissimilar metals must be at the same temperature
C. the junctions of any two dissimilar metals must be at different temperatures
D. reference junctions must be within 30 to one another

7. What temperature scales have 180 between the ice point and steam point of water?

   A. Rankine and Kelvin
   B. Celsius and Fahrenheit
   C. Kelvin and Fahrenheit
   D. Fahrenheit and Rankine

8. What temperature on the Rankine scale is equivalent to 212F?

   A. 672 R
   B. 685R
   C. 7080 R
   D. 729R

9. What temperature on the Celsius scale is equivalent to 68 F?

   A. 15C
   B. 20 C
   C. 25C
   D. 30 C

10. At what temperature do the Celsius and Fahrenheit scales indicate the same value?

   A. 40
   B. -10
   C. -3
   D. -40

LESSON 2. CALIBRATION AND USE OF TEMPERATURE STANDARDS

ACCP Subcourse Number MM 0483........ Thermometry

Lesson Objectives..................................... After studying this lesson you should have a basic knowledge of the standards used to calibrate temperature sensing devices. Be able to answer all review questions correctly pertaining to:

1. Platinum resistance thermometer.
2. Equiphase triple point of water cell.
3. Ice point calibration standard.
4. Constant temperature Baths.
5. Thermocouple.
6. Resistance thermometer.
7. Temperature measurement system.

Credit Hours.. Two hours

1. CALIBRATION REFERENCES

a. Primary Standards.
The primary standards are the platinum resistance thermometer and platinum-platinum rhodium (10) thermocouple.
The platinum resistance thermometers cover a range of -182.970˚¸C to 630.5˚¸ C and are calibrated against the following references:

Boiling point of oxygen........... -182.970˚¸C
Triple point of water............. 0.01000˚¸C
Freezing point of antimony........ 630.5˚¸C

The triple point of water is also called the equiphase of water, because at 0.01000˚¸ C, water coexists as liquid, solid, and gas (vapor). This is the most accurate temperature reference at present.
The freezing point of a substance is the temperature at which a liquid when cooled becomes a solid. Boiling point, however, is the temperature at which a liquid becomes a gas.
Calibration of the platinum-platinum rhodium (10) thermocouple, which is the international standard from 630.5˚¸C to 1, 063˚¸C, is referenced to the freezing points of antimony (630.5˚¸C) and gold (1, 063˚¸C) .

b. TEMPERATURE STANDARDS AND THE TRIPLE POINT OF WATER.
Fixed points which define international temperature scales are thermal states or temperatures uniquely defined and recognized by physical phenomena occurring

at those states or temperatures. Melting and boiling points of pure substances at specified pressures are typical examples.

The International Temperature Scale, adopted in 1927 by the Seventh General conference on Weights and Measures and revised in 1948, is based upon a number of fixed and reproducible equilibrium temperatures to which numerical values are assigned. These fixed points (degrees Celsius), at a pressure of one atmosphere, are:

Boiling point of oxygen	-182.970
Melting point of ice	0.
Boiling point of water	100.
Boiling point of sulfur	444.600
Freezing point of silver	960.8
Freezing point of gold	1063.0

The fully graduated scale is realized by interpolation instruments, namely, a strain-free, high-purity standard platinum resistance thermometer (-182.970˚¸C to 630.5˚¸C), a platinum/platinum-rhodium thermocouple (630.5˚¸C to 1063˚¸C), and a standard optical pyrometer (above 1063˚¸C).

Of these basic fixed points, standards laboratories have made greatest use of the ice point although limitations on its reproducibility by means of an ice bath have long been noted. For example, gradients may exist through out the ice bath, the materials may not be absolutely pure, and manipulative technique of personnel may contribute additional error. To a very significant degree, the Equiphase Triple Point of Water Cell overcomes those limitations of the ice bath. Since the triple point temperature is actually generated in the sealed inner glass container, the Equiphase Cell is not open to contamination as is the ice bath. This feature not only makes the cell independent of atmospheric pressure but also frees it from errors due to faulty operator technique. Recent measurements of the triple point of water have demonstrated reproducible results on triple point of water cells to 0.00008˚¸C. The International Advisory Committee on Weights and Measures has recommended that the zero of the International Temperature Scale should be defined as being the temperature 0.0100 degree below that of the triple point of water.

*All reference temperatures are referenced at standard atmospheric pressure.

2. EQUIPHASE TRIPLE POINT OF WATER CELL (Secondary reference standard)

The Equiphase Triple Point of Water Cell (see fig. 1) is a device for generating the stable temperature established when the solid, liquid, and vapor phases of water exist in thermal equilibrium. The triple point temperature of water is one of the fixed points definitive of both the International temperature Scale (0.0100˚¸C) and the absolute thermodynamic scale (273.16 K).

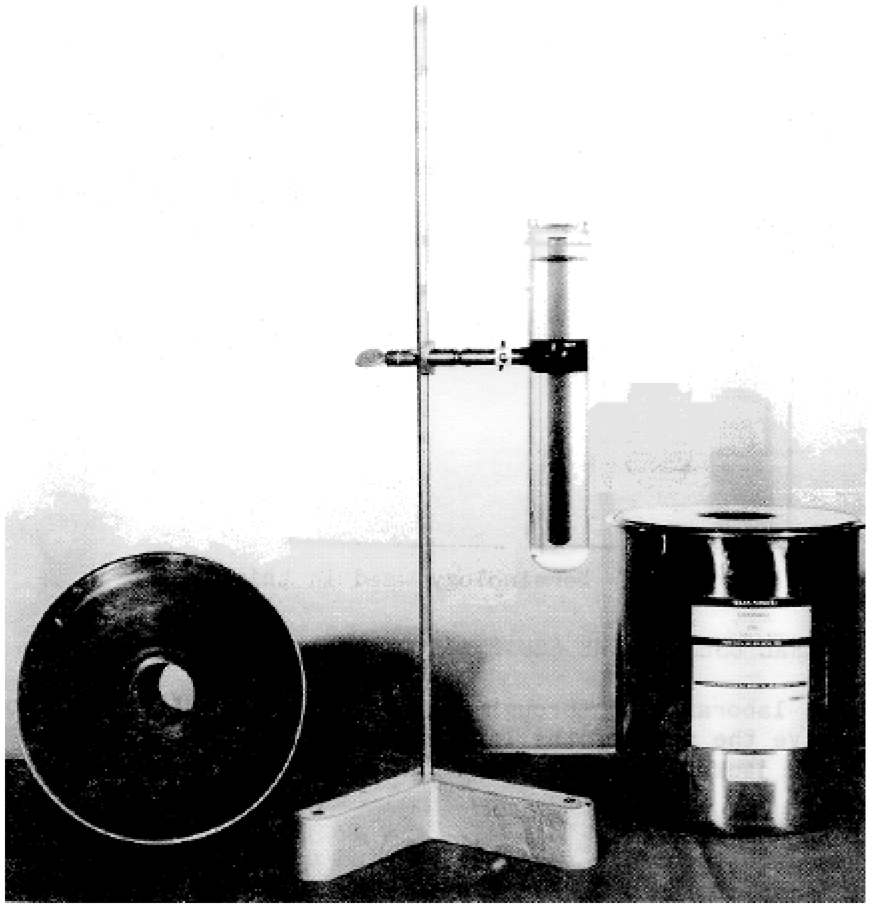


Figure 1. Equiphase Cell.

a. PHYSICAL DESCRIPTION. The heart of the Equiphase Triple Point of Water Cell is a cylindrical glass container or inner cell having a re-entrant tube which serves as a thermometer well. The inner glass cell is nearly filled with high-purity, gas-free water, and is evacuated to the required low pressure and sealed. Insulating material cradles the glass cell in a stainless steel jacket, providing both thermal insulation and mechanical protection. A removable cover protects and insulates the top part of the glass cell. The thermometer well is 10 mm in diameter and 35 cm in length and is designed to receive platinum resistance standard thermometers commonly in use. Partial freezing of the sealed-in water, following by partial melting, establishes the triple point temperature (0.0100C) which is transferred through the well to an inserted thermometer. The Equiphase Cell is made from the best commercial glass available - if scratch marks appear on its surface, however, there will be no effect on its operation or reproducibility.

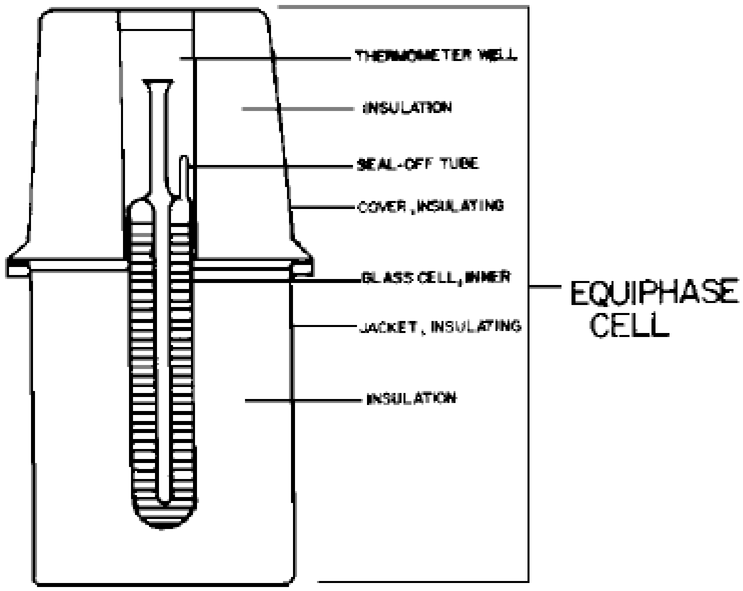


Figure 2. Terminology used in this lesson.

b. GENERAL USES OF THE EQUIPHASE CELL
Standards laboratories throughout the world use triple point of water cells to derive the zero of the International Temperature Scale. With its insulating jacket and cover, the Equiphase Cell is ideally suited for this purpose.
While the ice bath will continue to find use as a temperature reference, mainly because of its flexibility as to size, it should be compared to an Equiphase Cell whenever accuracy and precision are required. The Equiphase Cell may be used to check the accuracy of the ice bath by comparing the readings of a sensitive thermometer immersed in the ice bath and then transferred to the Equiphase Cell. The resistance ratio should be 1.0000398 in the case of a platinum thermometer. This ratio may vary by 1 digit in the least significant figure (corresponding to .025 millidegree) for different thermometers. In the case of a mercury thermometer, the difference in temperature should be +0.01˚¸C.
The Equiphase Cell makes an excellent reference junction temperature bath for thermocouples.
Convenience of the Equiphase Cell and its freedom from contamination suggest its use also in less demanding applications. Accuracy can be assured with personnel who have not had extensive training in the use of precision temperature standards.
c. PREPARATION. The Equiphase Cell should be placed on a laboratory bench in a cleared area affording the operator sufficient room to lift the cover off and place it down beside the cell. The following materials are required (See fig. 3).

(1) Solid carbon dioxide (dry ice).
(2) Alcohol such as methanol or ethanol.
(3) Thawing rod (supplied).
(4) Rubber insert for bottom of thermometer well (supplied).
(5) Thermometer which will fit into well. Well dimensions: 10 mm ID (3/8"), 35 cm long (14").

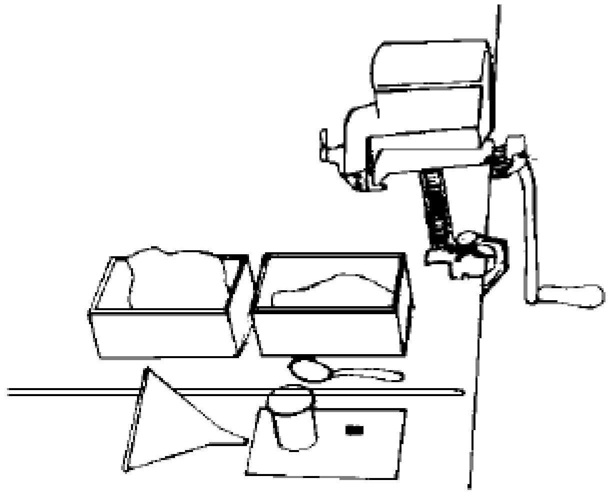


Figure 3.

Materials needed to prepare mantle. Solid dry ice (box at left) is run through grinder to obtain powder which is spooned through funnel into thermometer well. Thawing rod, small rubber insert, and alcohol are used during operation.

d. HANDLE WITH CARE. Do not shake or invert the Equiphase Cell vigorously. Violent agitation of the sealed-in water could break the inner glass cell.

e. DO NOT OVERFREEZE. When freezing the ice mantle, do not allow a heavy crust of ice to form across the surface of the water inside the glass cell. Bridging of the ice may be prevented by warming that portion of the glass cell with the hand while shaking the cell gently to agitate the surface of the water. Failure to take this precaution may result in a broken cell. Similarly, be sure that the mantle does not touch the glass at any point along the side or bottom of the cell.

f. PROCEDURES. Brief step-by-step instructions are included on the nameplate of each Equiphase Cell. These are intended mainly as a quick reference for personnel who have gained familiarity with the Equiphase Cell. They do not replace the more detailed procedures given below. Material in this subcourse should be thoroughly understood before an attempt is made to freeze the Equiphase Cell. Should any doubt arise as to proper procedure, contact your supervisor. Do not risk breaking a cell.

INSTRUCTIONS

To Establish Triple Point Temperature (0.01˚¸C):

- Remove cover and slowly invert cell to drain re-entrant well.
- To freeze cell, fill with powdered dry ice. Replenish until ice mantle forms around well.

CAUTION: Overfreezing will destroy cell. See detailed instructions.

- Add several cc of alcohol to well. Lower small piece of flexible material to bottom of well to prevent bottoming of thermometer on glass.
- Free ice mantle from well by lowering thawing rod (any room- temperature rod 3/8 inch max. dia.) into well. Repeat as necessary.
- Rotate cell. Ice mantle, when free, will rotate on well. Triple point temperature is now established and will be maintained until bottom of mantle melts, as evidenced by flotation mantle. (See figure 4)
- Replace cover.

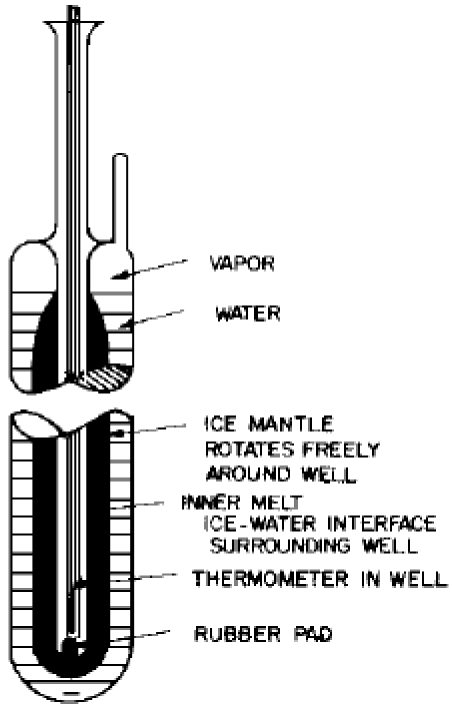


Figure 4. Terminology Relating to the triple point condition.

While the use of CO2 as a refrigerant is specified on the nameplate, alternate methods may be used. The actual method or refrigerant used makes no difference whatsoever as far as the actual triple point temperature is concerned so long as the criteria given below are carefully observed.

(1) FREEZING THE ICE MANTLE.

(a) Drain the thermometer well. (See figure 5) To do this, first remove the insulating cover from the Equiphase Cell. Grasp the cover with both hands and lift straight up to clear the inner glass cell. Then grasp the jacket with both hands and slowly invert, leaving the glass cell in its normal position in the jacket. Be certain that no water remains in the well. If there is any doubt, pour 2 to 3 cc of alcohol into the well, then invert and pour out the alcohol. The precaution against water is necessary because water in the well freezes and slows the freezing of the mantle. The result is an uneven mantle which will not last as long as a uniform mantle.

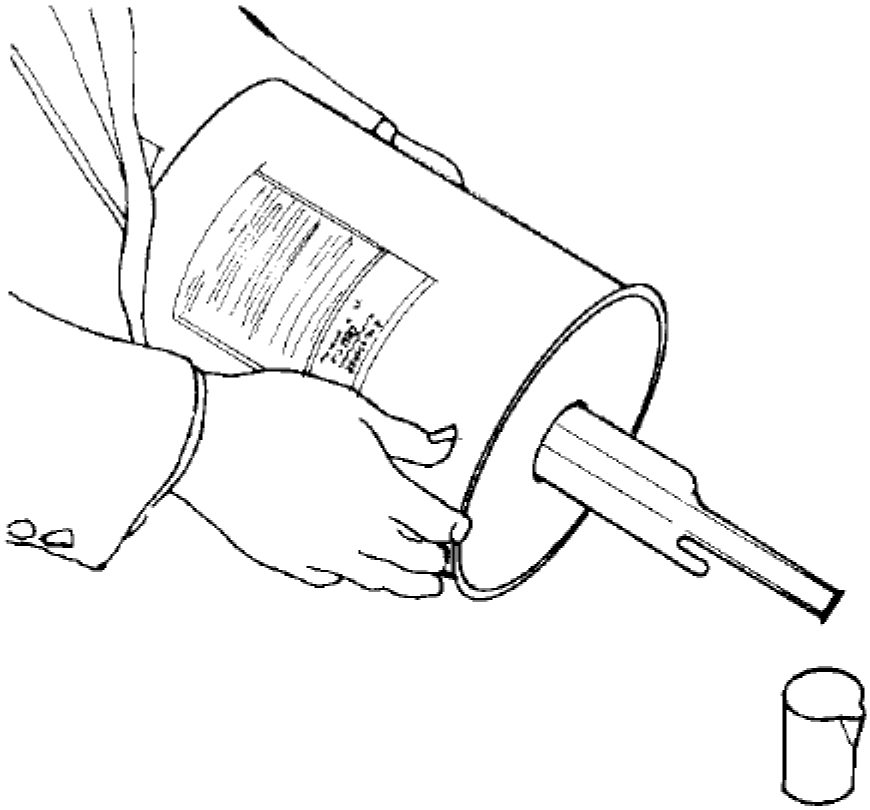


Figure 5. Holding cell in inverted position to drain.

(b) Refrigerate the inside of the thermometer well with powdered dry ice (solid C02).

The entire Equiphase Cell may be precooled by placing it in the food compartment of an ordinary refrigerator overnight. Other means of precooling can be used but it is important to avoid freezing of water in the glass cell. Precooling is not required but will result in maintaining the ice mantle for a longer period and will require less coolant to form the ice mantle initially.

CAUTION: Refer to para 2f(1) (a). The glass cell should be held in its container when the assembly is inverted for draining. This will eliminate the possibility of the cell's falling from the container.

Prepare powdered dry ice by pulverizing 1/2" to 2" chunks of dry ice in an ice crusher, grinder, or shaver to produce particles ranging in size from a fine snow to 1/16" diameter. Pour the dry ice into a plastic funnel held over the top of the thermometer well. Tap lightly on the side of the funnel to prevent the dry ice from blocking the funnel. Replenish frequently to keep the well reasonable full of dry ice. Gas evolution, particularly on first introducing the dry ice into the well, is vigorous and particles will be suspended in the gas stream. To prevent formation of gas pockets shake the cell gently. When the glass cell and the insulating jacket are at room temperature, it takes approximately 15 to 20 minutes to form a large ice mantle. The thickness of the mantle is not important provided it completely envelopes the well but does not touch the outer wall of the glass cell. A mantle 3 to 10 mm thick is satisfactory. When the water level in the glass cell has risen 1/8" to 1/4", a sufficient ice mantle will have formed. (See figure 6)

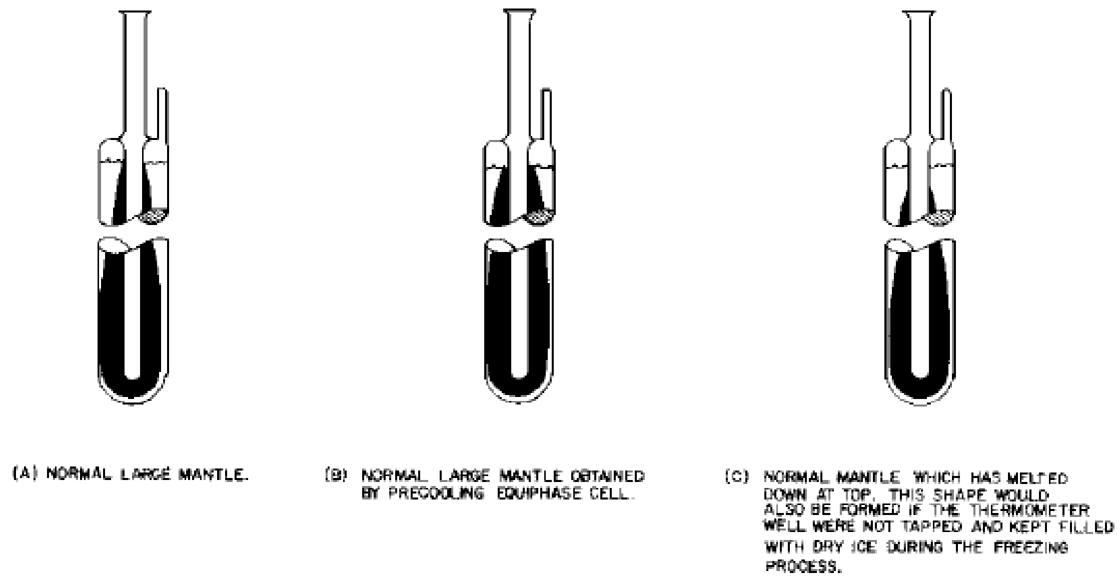


Figure 6. Ice mantle diagrams.

CAUTION: Avoid overfreezing. See para. 2e.

(c) When the ice mantle is frozen, pour out excess dry ice. Melt residues in the well by adding several cc of alcohol. The alcohol also serves as a heat transfer medium.

(d) The ice mantle may sometimes melt slightly at the top and recede below the surface of the water in a short period of time, while the rest of the ice mantle remains intact. In this event, the triple point temperature is not degraded significantly. The correction for height is inconsequential, (see para. 6, (c)(7), and any error introduced by the surface temperature of the water approximating room temperature may be neglected. (See figure 7)

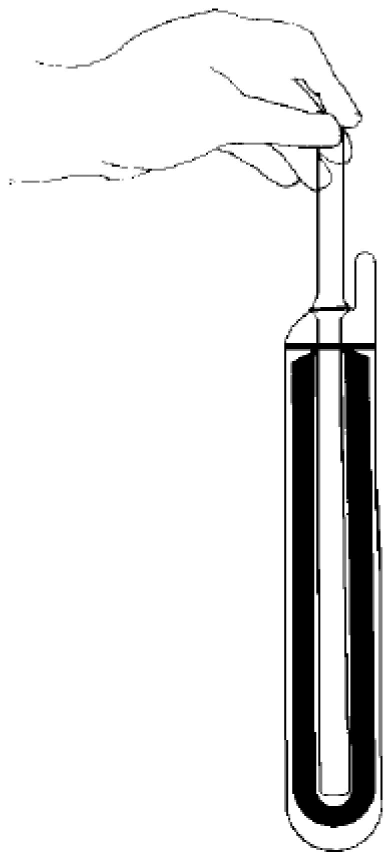


Figure 7. Example of good ice mantle.

The Equiphase Cell maintains the triple point condition as long as the bottom of the mantle has not melted and provided the mantle is free to rotate.

(2) THE INNER MELT. A very pure ice-water interface surrounding the thermometer well is formed by melting a thin layer of ice next to the well. This interface is generally referred to as the "inner melt." The ice mantle itself is purified to some extent by the freezing process. This results in a higher concentration of impurities in the water at the outside of the ice mantle with the purest ice next to the thermometer well.

(a) Lower the small piece of rubber to the bottom of the thermometer well to prevent bottoming of the thawing rod and thermometers on the glass (see figure 8).

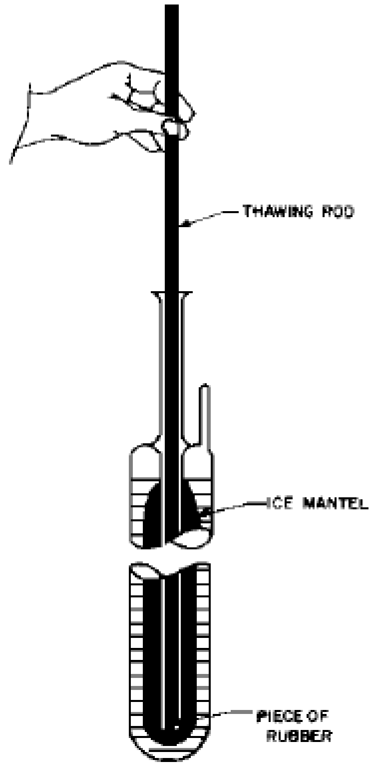


Figure 8. Thawing rod placed in well to form inner melt.

(b) Free the ice mantle from the well by lowering the thawing rod into the well. Repeat as necessary. Leave the thawing rod in the well only long enough to form the inner melt (5 to 10 seconds). To test, rotate the jacket. If free, the ice mantle will have clearly visible rotation on the thermometer well (see figure 9).

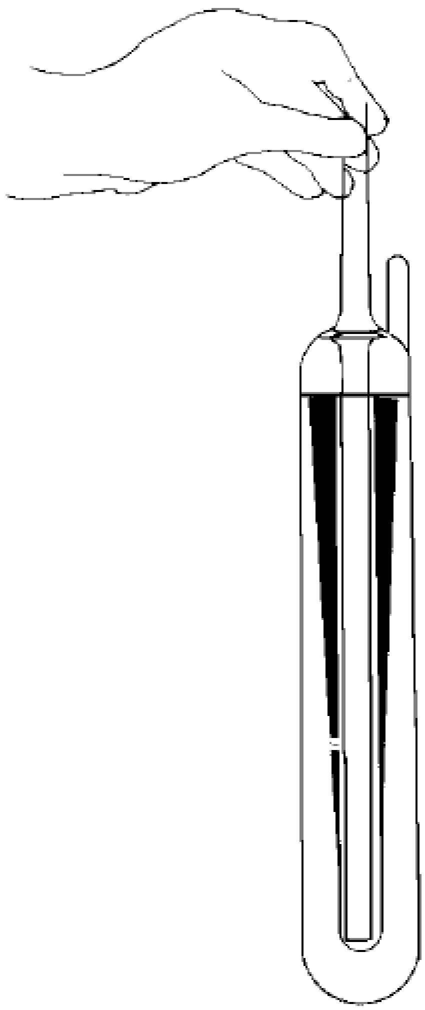


Figure 9. Melting of bottom of ice mantle and flotation.

(c) Triple point temperature: The 0.01C reference temperature is established as soon as the inner melt frees the ice mantle from the thermometer well. The triple point temperature is maintained until the bottom of the ice mantle melts. This is evidenced by flotation of the mantle, readily observable with the cover off.

(3) ALTERNATE METHODS OF FREEZING. A number of alternate methods of freezing the ice mantle can be suggested, using such materials as liquid nitrogen, a pre-cooled slurry of ice and salt, gases such as ammonia or CO2 discharged from a pressure source through a length of tubing in the thermometer well, or a flow of alcohol cooled by dry ice.

(4) PRESERVING THE ICE MANTLE. The ice mantle can be kept for several hours with the glass cell in its normal position in the insulating jacket.

If the ice mantle is to be preserved for a day or longer, the glass cell may be removed from the jacket and packed in ice inside a wide-mouth Dewar flask. Water forming from melting ice in the Dewar flask must be removed periodically.

An alternate method (preferred where convenient) is to leave the glass cell, with mantle, in its insulated jacket and pack the entire Equiphase Cell, including cover, in ice inside a larger container. Even in well-equipped labs, office wastepaper baskets may prove to be practical and effective for this purpose. Any water forming from melting ice must be removed from time to time.

In considering the length of time the ice mantle will be intact, note that water reaches its maximum density at +3.98˚¸C. This means that any water which is around 0˚¸C and becomes heated slightly will fall to the bottom of whatever container it is in. This is the basis for stating that the Equiphase Cell should not be used beyond the time at which the ice mantle floats.

Larger ice mantles can be preserved for a longer time than others and tend to melt more uniformly, partly because they impede somewhat the circulation of warmer and heavier water to the bottom of the cell.

(5) INSERTING THERMOMETERS (See figure 10). Any type of thermometer may be used with the Equiphase Cell provided it will fit into the thermometer well. Before inserting the thermometer, replace the cover over the top part of the cell. Thermometers should be chilled before insertion.

With the thermometer inserted into the well, there should be sufficient ice water or chilled liquid in the well so that the liquid level is above the top of the ice mantle. If the thermometer is frequently removed and replaced in the well, it should be pre-cooled before inserting so as to avoid excessive melting of the ice mantle.

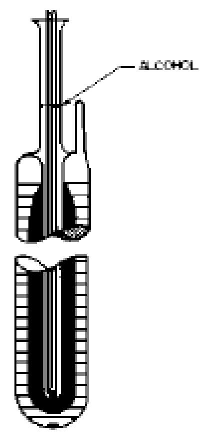


Figure 10. Thermometer in well with alcohol.

(6) TEMPERING THERMOMETER LEADS (See figure 11). Ice and water may be added through the opening in the cover to surround the top portion of the thermometer well in order to temper the thermometer leads and prevent heat conduction through the leads down into the well. It does not matter if this tempering ice bath spills over the well provided that no ice chips are forced down into the well.

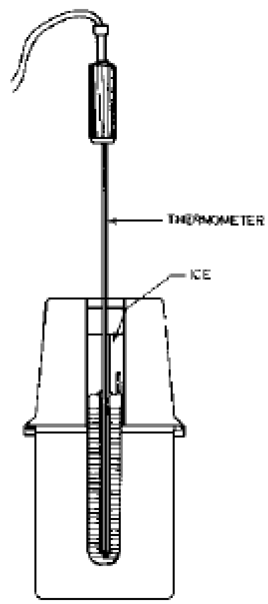


Figure 11. Tempering thermometer leads.

(7) TEMPERATURE CORRECTION FOR DEPTH. A small temperature correction may be applied to account for the head of the water above the center of the thermometer element. The temperature, tC, at the level of the thermometer can be determined from the equation:

$$tC = 0.0100 - 0.00000723 \times h;$$

where h is the height in cm from the level at the center of the thermometer element to the surface of the water in the glass cell.

(8) OPERATING PRECAUTIONS. The Equiphase Cell should be used in such a manner that a minimum of heat is introduced into the cell from outside sources. Heat may be conducted by thermometer leads or by the body of the thermometer or thermocouples when placed in the well. This may be prevented by packing ice around the upper portion of the well, and by chilling thermometers before insertion. Heat may also be introduced by the power supplied to the platinum resistance element. A self-heating error may be incurred if the thermometer is operated at a current in excess of its calibration current. The glass cell itself is transparent to heat and, if withdrawn from the insulating jacket during operation, (fig. 12) cannot prevent radiant heat from room sources from affecting the thermometer. This can be prevented by keeping the glass cell inside the insulating jacket during operation. In no case will the triple point temperature in the glass cell change. However, if the above precautions are not taken, and heat transfer into the well is permitted, then the temperature of the contents of the well will rise sufficiently to conduct this heat to the ice mantle. Then, in the case of devices such as platinum thermometers in partially evacuated envelopes, deviations of several millidegrees may be observed in the thermometer readings.

(9) TESTING THE EQUIPHASE CELL. The triple point of water is a fixed point, the temperature of which is a matter of definition, and therefore cannot be measured. There are tests, however, which can be used for a qualitative check of the triple point cell.

(a) COMPARISON OF TWO EQUIPHASE CELLS. Since the triple point temperature of water is a defining standard, an Equiphase Cell can best be checked for accuracy by comparing it to a second Equiphase Cell. If the two cells are free from air leak or any other contamination, no temperature difference between them will be observed. If a temperature difference is detected, the cell having the lower temperature contains impurities. This is so because the defining temperature of 0.0100˚¸ C is a theoretically calculated maximum value for the triple point of water.

(b) TEST OF INDIVIDUAL CELL FOR AIR LEAK (See figure 12). Test for air leak by tilting the Equiphase Cell, holding the seal-off tube down. If there is no significant air contamination, an audible "click"is heard, and the bubble trapped in the seal-off tube will diminish in volume by a factor of three or more as the cell is tilted slowly tofurther compress the bubble. A 3 to 1 reduction in the volume of the trapped air bubble means that the freezing point is lowered less than 50 microdegrees, a figure within the Equiphase Cell guarantee of .0005˚¸C by a factor of 10. In most cases the reduction in bubble size will be much greater than 3 to 1 (see figure 13).

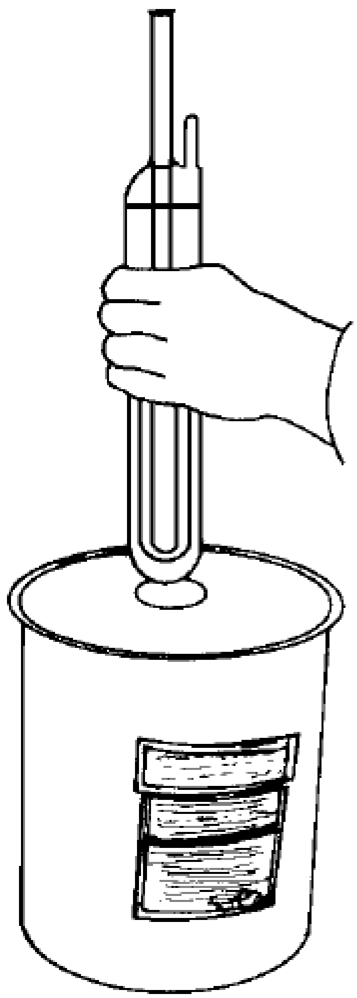


Figure 12. Removing inner glass cell from insulating jacket.

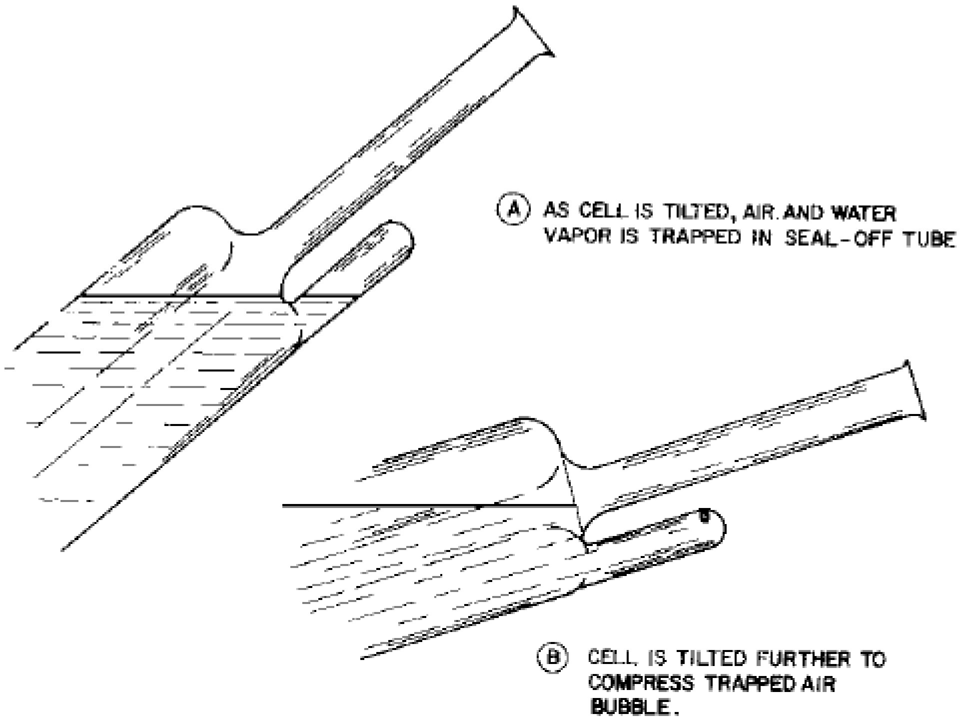


Figure 13. Tilting cell for air bubble test.

3. MODEL RCS1-SP-ICE-POINT CALIBRATION STANDARD (See figure 14).

a. DESIGN AND CONSTRUCTION.

(1) Materials. Material shall be free from all defects and imperfections that might affect the serviceability of the thermoelectric ice point.

(2) Reference well. The reference well has a minimum immersion depth of 150 millimeters, and an inside diameter of 10 millimeters. The reference well is metal and not subject to corrosion.

(3) Well liner. The thermoelectric ice point has a corrosion resistant metal reference well liner. The liner will provide a snug fit when inserted into the reference well and has a minimum inside diameter of 8.5 millimeters. The well liner is 6.25 inches in depth and closed at one end.

(4) Ice point indicator. The thermoelectric ice point has a pilot light for indicating when the unit has reached the ice point and stabilized.

(5) Power input requirements. The unit operates on 115 volts, 60 cycle AC, single phase and requires no more than 150 watts.

(6) Ice point control system. The unit has an automatic control system for maintaining the ice point cell at 0˚¸.

(7) Instrument housing. The unit has a metal housing with a carrying handle mounted on top. The complete assembly is no more than 14.0 inches in height, 9.0 inches in width, and 13.0 inches in depth.

(8) Instrument weight. The complete unit has a maximum weight of 40 pounds.

b. PERFORMANCE CHARACTERISTICS.

(1) Ice point stabilization time. The maximum time required for the ice point to reach 0˚¸ Celcius, with a temperature probe inserted in the reference well, and stabilize shall be 1.5 hours. The ice point is capable of stabilizing at 0˚¸ Celcius

within 30 minutes after a temperature probe, initially at ambient temperature, is inserted in the reference well.

(2) Stability. The ice point temperature in the reference well does not deviate more than ˚± 0.03˚¸ Celcius from 0˚¸ Celcius over a 24 hour period of continuous operation. The thermoelectric ice point is capable of reproducing the ice point (0˚¸C.) within ˚± 0.02˚¸ C when it is cycled through its freezing and thawing cycles.

(3) Service conditions. The equipment will operate satisfactorily under all of the environmental conditions specified herein.

(4) Operational environment. The equipment can be operated after stabilizing over the following range of environmental conditions:

(a) Temperature form 22˚¸ C. to 24˚¸ C.
(b) Relative humidity from 20% to 50%.
(c) Altitude from sea level to 10,000 feet.

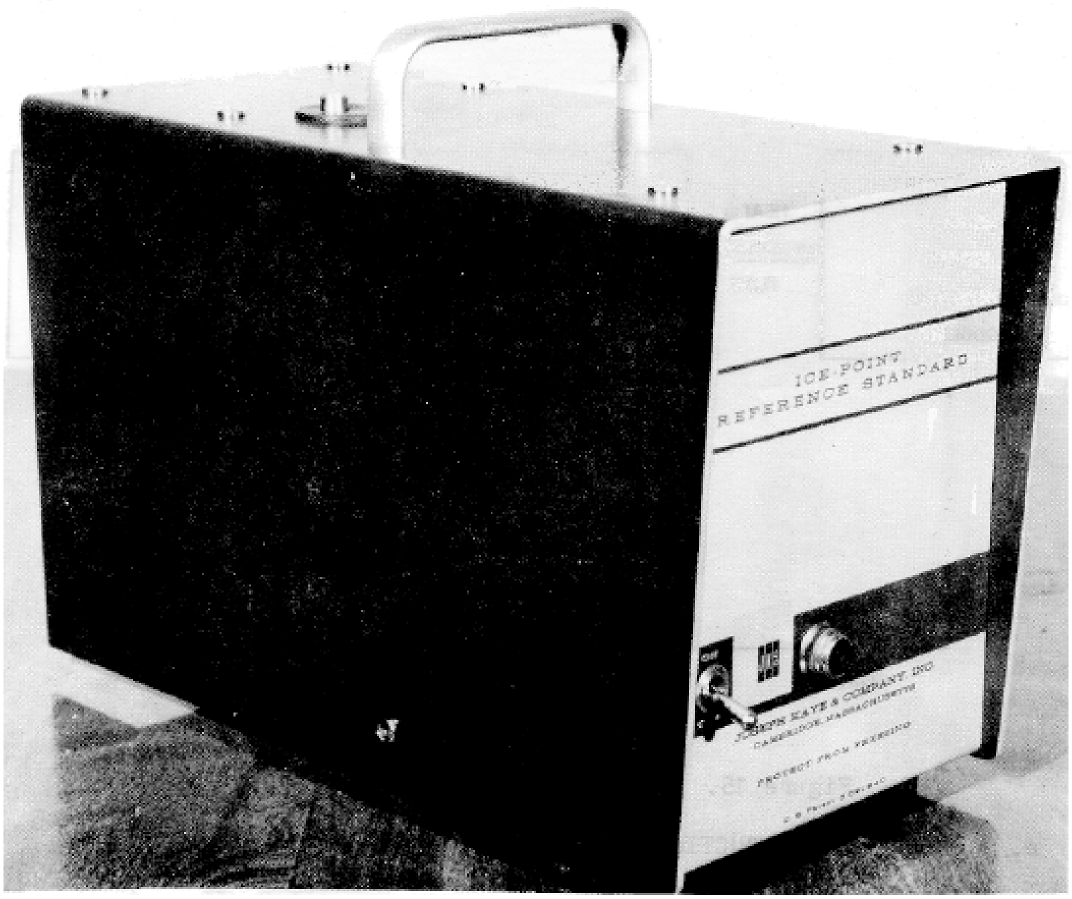


Figure 14. Ice point reference standard.

c. THEORY OF OPERATION. The instrument maintains the reference well at 0˚¸C continuously. The reference temperature of 0˚¸C is established by the physical equilibrium of ice and water within the sealed reference cell. The ice-water equilibrium is sustained by a thermoelectric cooler automatically controlled by a bellows-microswitch sensing mechanism which responds to the relative volumes of ice and water coexisting in the hermetic cell, thus the reference well and installed thermocouples, or other sensor, are continuously surrounded by an equilibrium ice-water mixture.

d. INSTRUMENT BLOCK DIAGRAM (See figure 15).

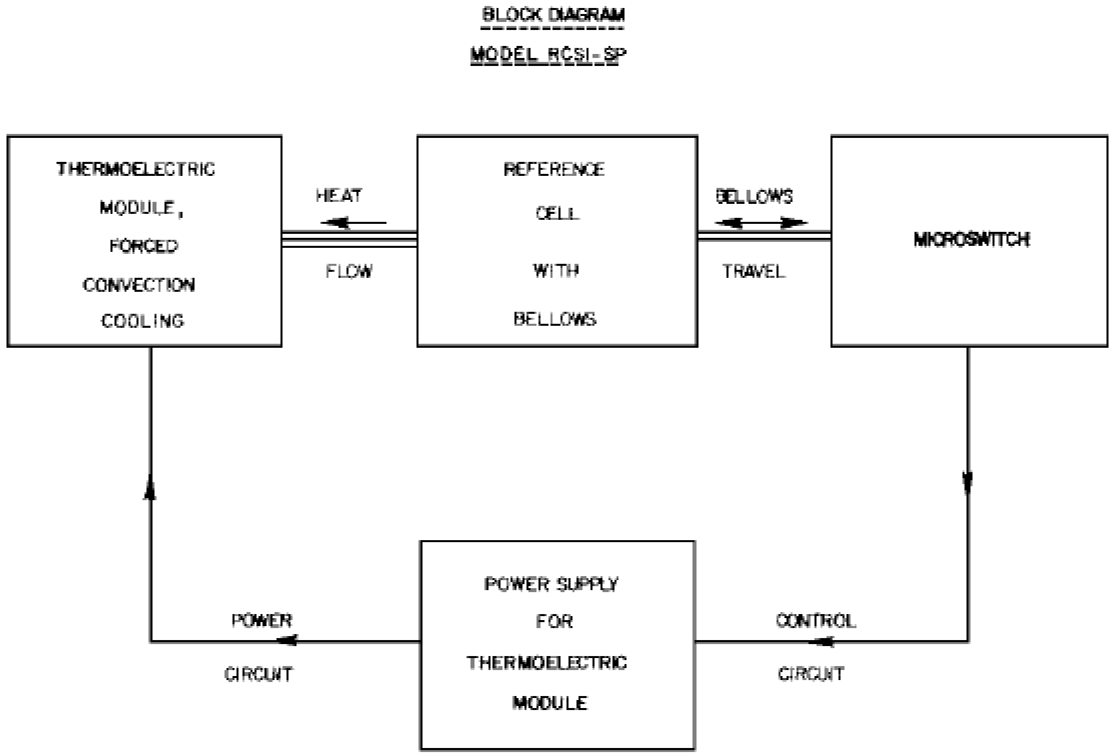


Figure 15. Block diagram model RCS1-SP.

e. OPERATING INSTRUCTIONS

(1) LINE SOURCE. Plug line cord into any 115 V, 60 cycle, grounded outlet.

(2) SWITCH. Turn the "ON/OFF" switch on the front of the reference unit to "ON". The pilot light should come on at this time.

(3) PULL-DOWN. Approximately 45 minutes after the unit has been turned on, the reference unit will start to cycle. This cycling will be indicated by the pilot light which will be alternately "On" and "off". (The pilot light is operated in parallel with the thermoelectric cooling module and, hence, indicates when the cell is being cooled).

(4) STABILIZATION. Once the pilot light has started to cycle, allow 10 to 15 minutes for the cell to stabilize. Your instrument is now ready for operation.

(a) Temperature form 22˚¸ C. to 24˚¸ C.

(5) USAGE. The unit is now ready for calibration use. When thermometers, thermocouples or resistance sensors are inserted into the reference well, the following steps must be observed in order to obtain accurate and repeatable results:

(a) Depth. All sensors must be inserted completely to the bottom of the well. If a sensor is stepped such that full well depth immersion is impossible, accuracy and repeatability of results must be evaluated, based on the users own experiments.

(b) Thermal Coupling. So that the inserted sensor is thermally coupled to the well, a close-fitting liner and non-corrosive oil should be used to fill the well so that all air spaces are removed. In the absence of a suitable liner, use oil to fill the well. Light mineral oil is suitable for this application. Coat the outside of the liner with oil before installing it into the well.

(c) Humid Environment Conditions. When operating in a humid environment, moisture will condense in the well and over a period of time displaces oil from the well. If noninsulated sensors (bare thermocouples) are inserted into the well, leakage resistance problems in the measuring circuit may arise. The use of a non-conductive insulator or the use of an oil with a specific gravity greater than one will correct this situation. Water in the cell will not damage or otherwise harm the cell.

(6) OPERATION, AND SHUT-DOWN. This instrument has been designed for continuous duty operation (24 hours a day, seven days a week). It is, therefore, unnecessary to turn the unit off at the end of each working day. When testing is complete, shut-down is accomplished merely by turning the switch to the "OFF" position.

f. INSTRUMENT CALIBRATION.

(1) INTRODUCTION. The recommended basis for calibration is that of a comparative technique between a freshly made well-maintained ice bath and the reference unit.

(2) DIFFERENTIAL THERMOCOUPLE. A continuous lead differential thermocouple, copper-constantan-copper, is a suitable sensor for use in calibrating this instrument as the sensor itself does not need calibration, as long as the gross wire characteristics have been substantiated. Initially, place both thermocouples into the freshly made ice-bath. Allow for stabilization and note any off-set on the read-out instrumentation.

NOTE: It is a requirement that read-out instrumentation be capable of resolving fractions of microvolt.

Remove one leg of the thermocouple from the ice bath and immerse it into the reference well. Make sure that oil is used to fill the reference well to the top. Any microvolt or fraction of microvolt off-set from the zeroed ice bath condition is a measure of the bath's deviation from true ice-point conditions. NBS circular 561 can be used to determine the thermocouple sensitivity.

(3) PLATINUM RESISTANCE THERMOMETER. A calibrated Platinum resistance thermometer fully inserted into the reference well can be used to establish its temperature. If the accuracy of the calibration and read-out equipment is such that there is any question about the overall reliability of the measurement, a comparative technique using a freshly made ice bath should be used.

g. INSTRUMENT MAINTENANCE CHECKS AND ADJUSTMENTS.

(1) Should pilot light replacement be required on an instrument having a miniature screw type bulb, a small piece of tape will prove helpful in grabbing the slippery bulb. The operation of the unit is entirely independent of the operation of the pilot light, hence the unit continues to operate when a bulb fails. The clicking

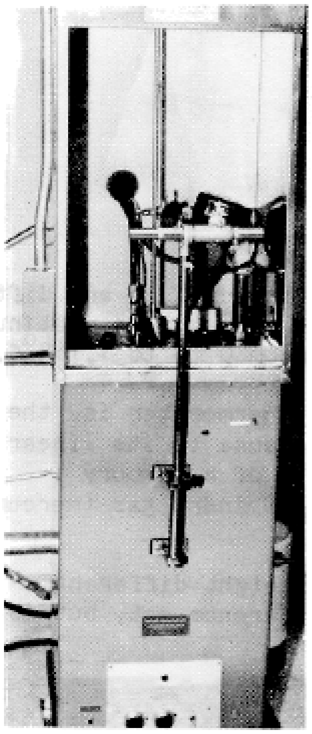
sound made by the microswitch can serve as an adequate cycling indication during the absence of a pilot light.

(2) The fan provides reliable performance for 2 to 5 years under favorable conditions of temperature and vibration without the necessity of oiling. Its life is inversely proportional to these factors. For example, at 110˚¸F, the fan may be expected to give reliable performance in excess of 5 years. If used in ambients of excessive heat, fan life may be extended by periodic oilings (a small amount once per year).

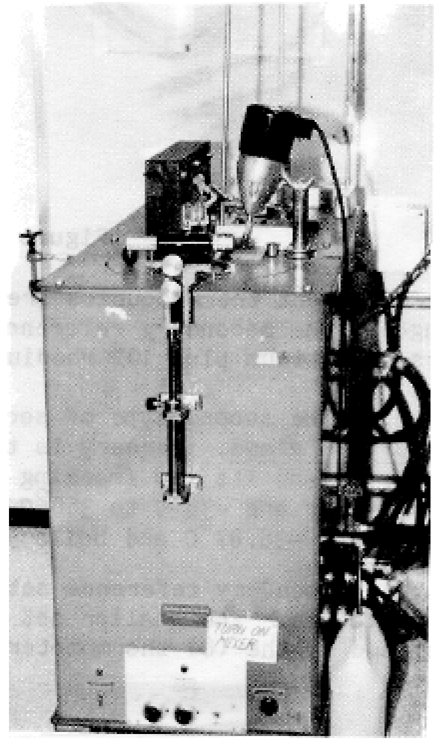
4. CONSTANT TEMPERATURE BATHS (See figure 16). (See figure 14).

a. The hot and cold baths (with accessories) are supplied as part of the secondary reference set. The hot bath has a range from ambient to 500˚¸F. The medium most used in the hot bath is a silicone based oil. The temperature of the bath is adjustable throughout its range through the use of calibrated controls located on the bath. The bath has a ready light that comes on when the pre-set temperature has been reached.

b. The cold bath is designed for continuous operation over the temperature range of from -40˚¸F to ambient using a 60% by volume solution of ethylene glycol in water as a bath medium. Temperature control is achieved by bucking a constant cooling capacity with a variable heat medium. High heat transfer rates and minimum temperature gradients result from the unique action of the dual jet-impeller stirrer employed to agitate the bath medium. Five heat capacities are available to provide optimum control at the desired operating temperature and may be selected by means of a heat switch located on the front of the bath housing.



A. Hot temperature bath.



B. Cold temperature bath.

Figure 16. Hot and cold baths.

5. Secondary Reference Temperature Standards (See figure 14).

a. The secondary reference standards for temperature indicating devices are classified into three types. The first is the thermocouple. As early as the 19th century an experimenter named Seeback discovered the thermal-electric effect. He twisted two copper wires and one iron wire together, placing one junction in ice water and heating the other, while connecting the other ends to an indicating device. He found this caused a current and called it the Seeback effect. The principle of operation for all thermocouple devices is based on the differences in junction temperature between any two dissimilar metals, thus producing an EMF.

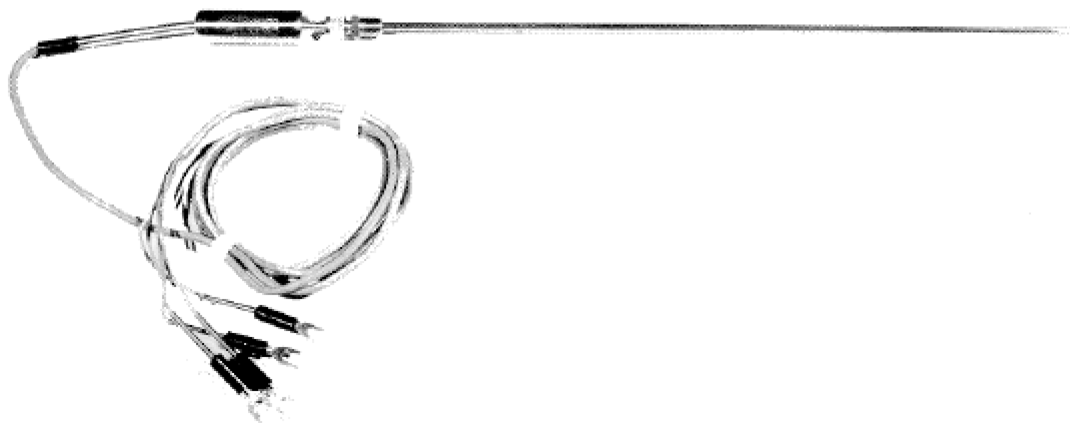


Figure 17. Thermocouple.

Different thermocouples are built for specific purposes and different ranges. The secondary reference thermocouple thermometer is platinum verses platinum plus 10% rhodium, with a range from 0˚¸C, to 1,768˚¸C.

b. The second type of secondary reference thermometer is, the mercury in glass. Mercury is the best liquid because to its linear expansion and its low freezing point. The limits of a mercury thermometer are -38˚¸C to 360˚¸C by the addition of inert gas (mercury freezes at -38.87˚¸C and boils 356.58˚¸C.)

The secondary reference set is shown here as eight different thermometers. The smaller set is a secondary reference set, but is being replaced by the (8) thermometer set.

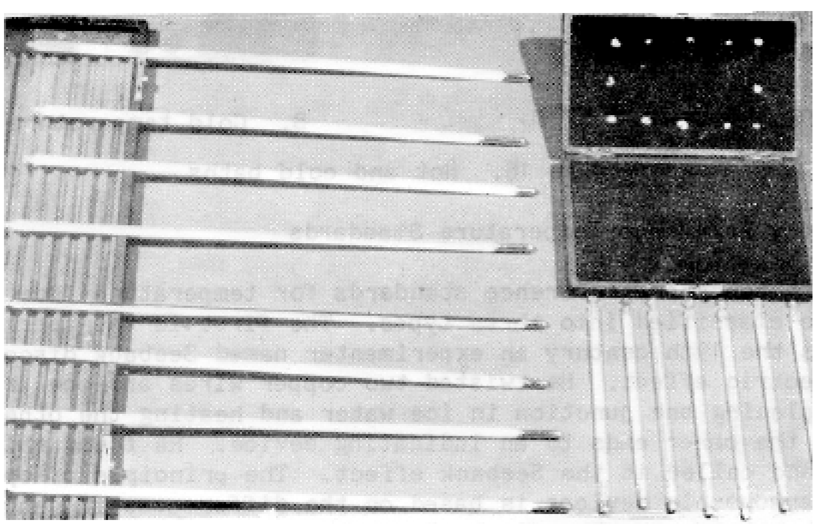


Figure 18. Thermometer set.

The range of each thermometer.
(1) -38˚¸C to +2˚¸C
(2) -8˚¸C to +32˚¸C
(3) +25˚¸C to +55˚¸C
(4) +50˚¸C to +80˚¸C
(5) +75˚¸C to 105˚¸C
(6) +90˚¸C to 155˚¸C
(7) +145˚¸C to +205˚¸C
(8) +195˚¸C to +305˚¸C
NOTE: There are other sets of thermometers listed in the the supply catalogs, however, this set is representative of the others.
c. The third type of secondary reference thermometer is the resistance thermometer. The principle of operation of the resistance thermometer has been discussed before. Here we have a platinum resistance thermometer and the Mueller Bridge, model E-1003.

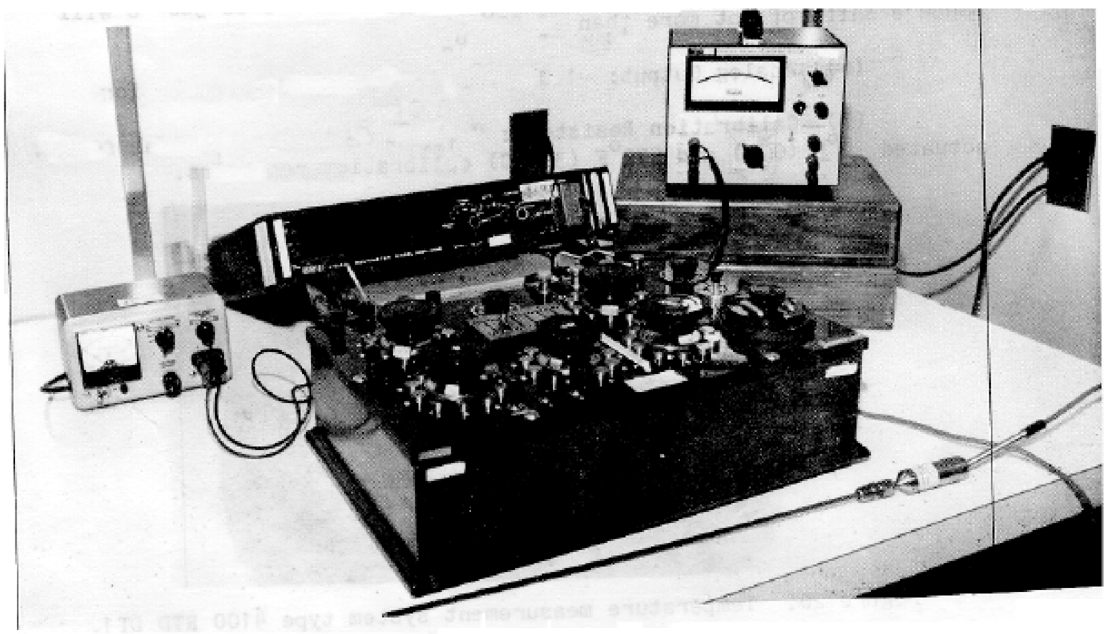


Figure 19. Typical equipment hook up for resistance temperature measurement.

6. TEMPERATURE MEASUREMENT SYSTEM TYPE 4100 (Refer to figure 20)

a. INTRODUCTION. The INSTRULAB 4100 has been designed specifically to meet the electrical, mechanical and environmental specifications of U. S. Army Materiel Readiness Command, Redstone Arsenal.
b. ELECTRICAL SPECIFICATIONS
(1) Ranges: -75˚¸ to 600˚¸F with 0.1˚¸F resolution and -60 to 300˚¸C with 0.1˚¸C resolution. Ranges shall be selectable with front panel switch.
(2) Display: Minimum four (4) digits plus sign, decimal and unit ID.
(3) Sample Rate: Minimum, 2 readings per second.
(4) Accuracy: ˚±(0.2˚¸F or 0.1˚¸C + 0.1 % of reading) (unit to be matched to sensor)
(5) Repeatability:

(a) Readout: ˚±1 least significant digit

(b) Sensor: repeated cycling from 0˚¸C to 300˚¸C will cause a shift of not more than ˚±0.05˚¸ at 0˚¸C.

(6) Analog Output: 1.0 mV/˚¸F or ˚¸C with 0.1 resolution

(7) Calibration Resistors: Display unit has integral switch actuated 32˚¸F (0˚¸C) and 572˚¸F (300˚¸C) calibration resistors.

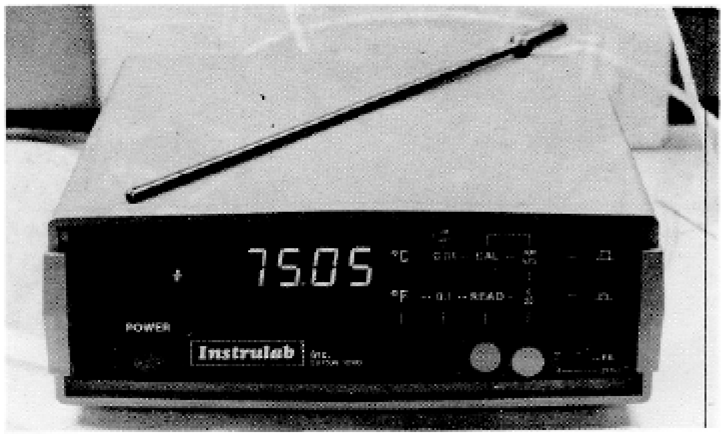


Figure 20. Temperature measurement system type 4100 RTD DT1.

(8) Reliability: Mean time between failure (MTBF) - 4200 hours. A failure is defined as any malfunction that occurs to place an operational position outside of the defined specifications.

(9) Calibration Cycle: This unit shall maintain specified accuracies for a minimum of 360 days.

(10) Probe:

(a) Type - Platinum Resistance

(b) Probe resistance - 100 ohms at 0˚¸C.

(11) Power: Battery powered with integral battery charger circuit and plug-in AC adapter.

(a) Battery - rechargeable with easily removable spring tension or clip-on type terminal contacts. Battery shall last a minimum of four (4) hours continuous operation before requiring recharging.

(b) AC adapter - will operate from either 115V or 230V, AC, 50-60 Hz power. The unit will operate in a temperature measuring mode and charge the battery at the same time.

c. MECHANICAL SPECIFICATIONS.

(1) Weight: 5.5 pounds.

(2) Size: 8-1/2"W x 3-1/4"H x 9-1/2"L

(3) Probe

Length - 10 inches

Diameter - 3/16 inch

d. ENVIRONMENT SPECIFICATIONS

(1) Operational conditions:

(a) Temperature +4˚¸C to 40˚¸C.

(b) Relative humidity 0 per cent to 90 per cent

(c) Altitude 0.0 to 10,000 feet above sea level.

(2) Storage and Transit. The equipment was tested to meet all performance requirements as specified herein after being subjected to the following conditions and returned to the range of operational conditions specified herein.

(a) Stored for 12 hours at 55˚¸C.

(b) Stored for 12 hours at +60˚¸C.

(c) Stored for 12 hours at 40,000 feet above sea level.

(3) This instrument also passed acceptance tests for shock, drop and vibration.

(4) AMBIENT TEMPERATURE EFFECT: 25˚¸C reference. Temperature coefficient of 0˚¸C; ˚±0.01˚¸C/˚¸C. Temperature coefficient of span: ˚±0.005% of reading per ˚¸C.

e. OPERATING INSTRUCTIONS

(1) After having unpacked this instrument, carefully examine it and any enclosed accessories for physical damage and compliance with Packing List. If any of the articles are missing or damaged, inspect the packing case for signs of damage or theft during shipment and immediately report it to carrier.

(2) Remove the four (4) 6-32 screws on the bottom of the case. Holding the case together, turn over and gently remove top cover.

(a) Visually make sure that all wires to battery and to transformer are in place.

(b) Check that the display board is seated in its connector properly

NOTE: There is no need to perform any adjustments to the instrument. The instrument is factory calibrated and burned in, prior to ship- ment, and is designed to remain in calibration for a minimum of twelve (12) months before recalibration is required.

(3) Back Panel connectors and switch.

(a) Sensor input connector: the input sensor is connected here. Be sure to match the sensor with the unit, as each unit is calibrated to a particular sensor.

(b) Analog out connector: a buffered analog output (3 mA. maximum) of 1 mV per degree is available on this connector. The analog output corresponds to the engineering units of the readout.

(c) Input voltage selector switch: This switch is a slide switch that changes the battery charging circuitry from a 115V, 60 Hz. input to a 220V, 60 Hz. input.

(d) Power cord: The power cord connects the line power to the battery charger, through a 1/8 AMP Slo Blo fuse.

NOTE: Whenever the power cord is connected to line power, the battery is charged, regardless of power switch state.

(4) Front panel controls and indicators.

(a) Power switch: The power switch disconnects the battery power from the DTI circuitry and therefore turns the unit off.

NOTE: The power switch does not disconnect the line power from the battery charger. (see 5e (3) (c).

(b) Indicators: There is a small 1.e.d. behind the "˚¸F" and the "˚¸C" marking on the front panel to indicate the engineering units of the readout.

(c) "˚¸F" and "˚¸C" switch: This is a "push/push" switch. When this switch is "in", the engineering units of the readout are in Fahrenheit and the scale of the Analog Out is 1 mV per ˚¸F. When this switch is "out", the engineering units of the readout are Centigrade and the scale of the Analog Out is 1 mV per ˚¸C.

(d) ".01 & .1" switch: This is a "push/push" switch. When this switch is "in", the readout is in tenths (0.1) of a degree; either Fahrenheit or Centigrade as determined by the "˚¸F & ˚¸C" switch. When this switch is "out", the readout is in hundredths (0.01) of a degree, either Fahrenheit or Centigrade, as determined by the "˚¸F & ˚¸C" switch.

NOTE: In the hundredth (0.01) degree position, the unit is not designed to measure greater than 100˚¸C or 232˚¸F.

(e) "Cal & Read" switch: This is a "push/push" switch. When this switch is "in", the readout indicates the temperature at the sensor. The sensitivity is determined by the "01. & .1" switch. The engineering units are determined by the "˚¸F & ˚¸C" switch. When this switch is "out", the readout should indicate the temperature as determined by the "300/572 & 0/32" switch. (see 5e (4) (f)

(f) "300/572 & 0/32" switch: This is a "push/push" switch. When this switch is "in" (see note) the readout should read 0˚¸ C or 32˚¸ F, depending on the position of the "˚¸F & ˚¸C" switch. The ".01 &.1" switch determines sensitivity. When this switch is "out", the readout should read 300˚¸C or 572˚¸F, depending on the position of the ˚¸F & ˚¸C" switch.

NOTE: The ".01 & .1" switch must be "in" at this time. The "Cal & Read" switch must be "out" for this switch to have any effect.

(5) Battery Charging.

(a) Unit must be plugged in for a minimum of twelve (12) hours to insure a fully charged battery, before using it without line power.

(b) The unit will operate while the battery is being charged.

(c) When using this instrument on battery power alone, the battery should be checked before and after each important measurement.

f. OPERATING PROCEDURES.

(1) Press Power switch "on". Display should light up.

(2) Check the battery by checking calibration at 572˚¸F (see 5e

(3) Allow fifteen (15) minutes warm-up.

(4) Set Front Panel switches to desired sensitivity and engineering units. (see 5e (4).

(5) Push the "Cal & Read" switch "in".

(6) Place the probe into the atmosphere under test and allow a ten second settling time.

(7) Read temperature directly on readout.

g. THEORY OF OPERATION.

(1) Introduction.

The 4100 DTI converts the resistance of a calibrated RTD sensor to a digital Light Emitting Diode (LED) display in degrees Celsius or Fahrenheit and a corresponding analog output voltage, selectable by a Front Panel Switch. The

4100 DTI uses Instrulab's patented RTD linearizing circuit with a dual slope A-D converter with auto-zeroing, to provide an accurate, stable reading.

(2) Block diagram analysis.

Refer to the simplified block diagram, Fig. 2-21.

The 4100 DTI consists of four (4) sections:

(a) Sensor and analog signal conditioner
(b) A-D converter and display
(c) Battery and battery charger
(d) Power supply.

(3) Sensor and analog signal conditioner.

To minimize errors due to lead wire resistance, the sensor is supplied with a four (4) wire lead configuration, two leads to each end of the RTD element. One pair of leads (one to each end of the RTDF element) supplies a current which results in a voltage across the RTD element. This voltage, sensed by the other pair of leads, is converted to either a 1 millivolt per degree Celsius (for 0.1 degree resolution) or a 10 millivolt per degree Celsius (for 0.01 degree resultion) signal for the A-D converter.

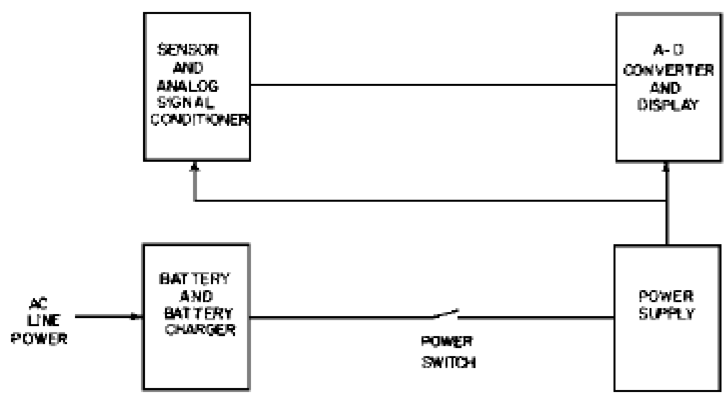


Figure 21. Simplified Block Diagram.

his voltage is also converted into either a 1 Millivolt per degree Celsius or a 1 millivolt per degree Fahrenheit analog output voltage.

(4) A-D converter and display (Fig. 22)

The basic 100 microvolt per LSD (least significant digit) sensitivity provides 0.1 degree Celsius resultion for the 1 Millivolt per degree Celsius input and 0.01 degree Celsius resolution for the 10 Millivolt per degree Celsius input. To provide Fahrenheit readings, the input signal is multiplied by 1.8 (by extending the integrate input state) and offset by 32 degrees (by presetting an Up/Down counter). Refer to the A-D converter timing diagram, (Fig. 22). The A-D converter has three states:

(a) Auto-zero
(b) Integrate input
(c) Integrate reference

(5) Auto-zero

This state starts at the end of the previous conversion cycle. If the unit is connected to AC line power, the start of this state is synchronized to the line frequency. During this state, the offsets of the buffer, integrator and comparator are stored on the auto-zero capacitor.

(6) Integrate input

During this state, the input signal is applied to the A-D converter. Since the offsets are stored on the auto-zero capacitor, the integrator's slope is determined solely by the input voltage. To display Decrees C, the input signal is integrated for 83.3 ms. Thus, the integrator output reaches a value proportional to the input signal and the fixed integrate time. To display degrees F, the input signal is integrated for 150 ms. Since the output of the integrator is proportional to both the input signal and the integrate time, this effectively multiplies the input by 1.8 (150/83.3).

(7) Integrate reference

At the end of the integrate input state, the comparator output depends on the polarity of the input signal. The polarity flip-flop is latched at the beginning of the integrate reference state and the reference voltage of the opposite polarity integrated. This causes the integrator to ramp towards its quiescent (auto-zero) point at a slope dependent on the reference voltage. When the quiescent level is reached (zero-crossing), the display is updated and the A-D converter automatically reverts to the auto-zero mode until the end of the conversion cycle. The time required to reach zero-crossing is proportional to the input signal.

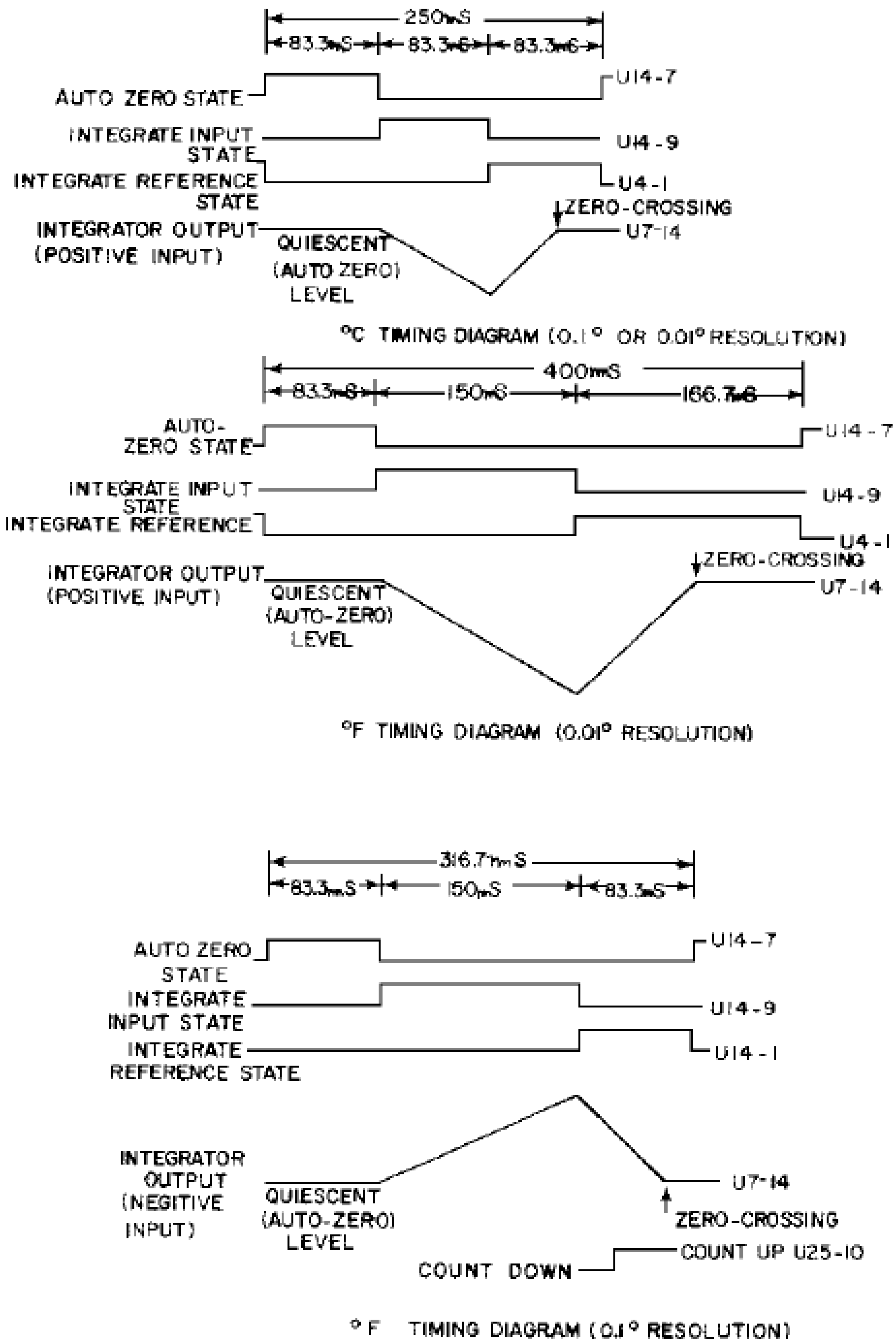


Figure 22. A-D converter and display.

To display degrees C, the Up/Down counter is preset to 0 degrees during the integrate input state. During the integrate reference state, the counter counts up at a fixed clock rate until zero-crossing. The clock rate and reference voltages are such that the display corresponds to the temperature of the sensor (e.g. 5000 counts equal 50.00 degree C for 0.01 degree resolution, 2500 counts equals 250.0 degree C for 0.1 degree resolution).

To display degrees F, the Up/Down counter is preset to 32 degrees during the integrate input state. For temperatures 32 degrees F and above (i.e. positive input signals), the counter counts up from 32˚¸ at the fixed clock rate during the integrate reference state until zero-crossing. The updated display corresponds to the temperature of the sensor in degrees F, since a 32˚¸ offset has been added and the input signal has been multiplied by 1.8 during the integrate input state (degree F = 1.8 degree C +32). For temperature less than 32˚¸F (i.e. negative input signals), the counter counts down from 32 degrees at the fixed clock rate during the integrate reference state until either zero-crossing or the counter contents are zero. Whichever occurs first. If zero-crossing occurs during this time (i.e. if the temperature of the sensor is between 32˚¸F and 0˚¸F), the display is updated with the polarity inverted, since the input signal was negative but the actual temperature of the sensor in degrees F is positive. If the contents of the counter become zero (i.e. if the temperature of the sensor in degrees F is negative), the counter then counts up from zero until zero-crossing. The updated display corresponds to the temperature of the sensor, (e.g. -4000 counts equals -40.00 degrees F for 0.01 degree resolution.

(8) Battery and battery charger

The battery charger circuit charges the battery whenever the unit is connected to AC line power (see 5e (3) (c). The power switch connects a nominal 7 volts to the power supply when the unit is turned on.

(9) Power supply

The LED display is powered directly from the nominal 7 volt input. The analog signal conditioner and the A-D converter are powered from an inverter circuit. It supplies 3 regulated outputs:

(a) Positive 15 volts

(b) Negative 15 volts

(c) Positive 5 volts

7. CALIBRATION PROCEDURE FOR SELF-INDICATING THERMOMETERS (CELSIUS AND FAHRENHEIT)

a. Test Instrument Identification

This procedure provides instructions for the calibration of Self-Indicating Thermometers (Celsius and Fahrenheit). Federal specification GG-T-336, MIL-T-1344A and NBS Monograph 90 were used as the prime data source in compiling these instructions. The thermometers will be referred to as the "TI" (test instrument) throughout this procedure.

(1) Model Variations. Thermometer types vary in range, accuracy and immersion depth. This is a general procedure covering Celsius and Fahrenheit thermometers.

(2) Time and Technique. The time required for this calibration is approximately 2 hours, using the physical technique.

b. Calibration Description

TI parameters and performance specifications which pertain to this calibration are listed in table 1.

Table 1. Calibration Description.

Test Instrument Parameters.	Performance Specifications.
Temperature	Range: –5 to +100°C Accuracy: Depends on range and type.
Temperature	Range: –31 to +212°F. Accuracy: Depends on range and type.

c. Equipment Required

Table 2 identifies the specific equipment used in this calibration procedure. This equipment is issued with secondary transfer calibration standards set 4931-621-7877 and is to be used in performing this procedure. Alternate items may be used by the calibrating activity when the equipment listed in table 2 is not available. The items selected must be verified to perform satisfactorily prior to use and must bear evidence of current calibration. The equipment must meet or exceed the minimum use specifications listed in table 2. The accuracies listed in table 2 provide a four-to-one accuracy ratio between the standard and TI. Where the four-to-one ratio cannot be met, the actual accuracy of the equipment selected is shown in parenthesis.

d. Accessories Required

The accessories listed in table 3 are issued with secondary transfer calibration standards set 4931-621-7877 and are to be used in this calibration procedure. When necessary, these items may be substituted by equivalent items unless specifically prohibited.

Table 2. Minimum Specifications of Equipment Required.

Item	Common Name	Minimum Use Specifications.	Manufacturer, Model, and Part Number.
A1	THERMOMETER[1]	Range: –31 to +124°F Accuracy: ±0.7°F	(8032312)
A2	THERMOMETER[2]	Range: 90 to 260°F Accuracy: ±0.5°F	(ASTM61F)

[1]Total-immersion thermometer.
[2]Partial-immersion thermometer.

Table 3. Accessories Required.

Item	Common Name	Description and Part Number
B1	CONTAINER	Approximately 6 in. in diameter and at least 8 in. in height, able to withstand 250°F. (6640–545–8512).
B2	HOTPLATE[1]	Approximately 6 in. in diameter having 250°F temperature elements
B3	SUPPORT STAND[1]	Thermometer support

[1]Additional equipment required.

e. Preliminary Instructions

(1) The instructions outlined in this section are preparatory to the calibration process. Personnel should become familiar with the entire procedure before beginning the calibration.
(2) Items of equipment used in this procedure are referenced within the text by common name and item identification number as listed in tables 2 and 3. For the identification of equipment referenced by item numbers prefixed with A, see table 2, and for prefix B, see table 3.
f. Equipment Setup
NOTE: Avoid unnecessary drafts on standard thermometer and TI during calibration.
(1) Remove TI from protective case.
(2) Inspect TI for foreign matter and evidence of deterioration
(3) (This step is for liquid-in-glass thermometers only.) Hold TI in vertical position. If bulb and column are not free from gas bubbles and stem is not free from globules of liquid, perform following steps if applicable.
(a) Eliminate gas bubbles in TI bulb by cooling with dry ice or equivalent coolant until liquid is drawn into bulb. Tap TI gently against pad of paper or against palm of hand. Bubbles should rise to surface and disperse.
(b) Eliminate gas bubbles from stem of TI by slowly and carefully heating bulb until bubbles are joined. Carefully tap TI against pad of paper or against palm of hand.

CAUTION

To avoid damage to TI, exercise extreme care when applying heat. Damage may result if thermometer or or bulb is overheated.
(c) Eliminate globules of liquid inside TI stem by carefully and slowly heating TI bulb until liquid column merges with globules.
NOTE: If globules tend to unite and reappear after bulb cools, obstructions or oxidation of mercury may be present and TI must be rejected.
g. Calibration Process
NOTE: Unless otherwise specified, verify the results of each test and take corrective action whenever the test requirement is not met before continuing with the calibration.
NOTE: The range of the standard thermometer overlap. Select the standard thermometer with the best accuracy for the specific temperature check to be made.
h. Ambient Temperature
(1) Performance Check
(a) Place TI and appropriate standard thermometer (A1 or A2) side by side in vertical position, using support stand (B3). Allow approximately 15 minutes for TI to stabilize.
(b) Compare indication of TI and standard thermometer and record the difference.
NOTE: The temperature conversion formulas below may be used:
$F = (C \times 9/5 + 32)$
$C = 5/9 \times (F-32)$
(c) Repeat (b) above twice.
(d) Average the three indications recorded in (b) above. The average will not exceed a value four times greater than the accuracy of the standard

thermometer, or a value greater than one scale division of the TI, whichever is greater.

(2) Adjustments. No adjustments can be made. A correction chart may be prepared, if requested by the customer.

i. Boiling Point.

(1) Performance Check

(a) Using support stand (B3), arrange appropriate standard thermometer and TI in vertical position so that each is supported in container without touching sides or bottom.

(b) Pour water into container (B1) until water level reaches 100˚¸C (212˚¸F) graduation point or etched immersion line on stem of thermometer.

(c) Immerse stem of TI to proper depth.

NOTE: Full-immersion type thermometers will be inserted to a depth sufficient to cover 100˚¸C (212˚¸F) graduation. The mercury column must be as near the liquid surface as possible. Partial-immersion type thermometers will be inserted to the depth of the immersion line etched on the stem.

(d) Place container on hotplate (B2). Position thermometer and TI for best advantage and energize the hotplate.

(e) Heat contents to boiling point, or to the desired temperature.

(f) Lift thermometer and TI slightly above waterline to the checkpoints position. Make a comparison observation of standard and TI and record the difference.

(g) Repeat (5) and (6) above twice.

(h) Average the three indications recorded in (6) above. The average will not exceed a value four times greater than the accuracy of the standard thermometer, or a value greater than one scale division of the TI, whichever is greater.

(i) De-energize hotplate and remove thermometers.

(2) Adjustments. No adjustments can be made. A correction chart may be prepared, if requested by the customer.

j. FINAL PROCEDURES

(1) De-energize and disconnect all equipment and replace test instrument within protective cover.

(2) In accordance with TM 38-750, annotate and affix DA Label 80 (U.S. Army Calibration System). When the test instrument cannot be adjusted within tolerance, annotate and affix DA Form 2417 (Unserviceable or Limited Use tag).

8. CALIBRATION PROCEDURE FOR THERMOMETER SETS 7910479 AND ASTM 80-182 (80-211-22); AND THERMOMETERS, FISHER SCIENTIFIC MODELS 15-142D AND 15-142F AND THERMOMETER ASTM 50F AND THERMOMETER 7913469

a. Test Instrument Identification

This procedure provides instructions for the calibration of Thermometer Sets 7910479 and ASTM 80-182 (80-211-22); AND Thermometers, Fisher Models 15-142D and 15-142F and Thermometer ASTM 50F and Thermometer 7913469. The manufacturer's instruction manual was used as the prime data source in compiling these instructions. The equipment being calibrated will be referred to as the "TI" (test instrument) throughout this procedures.

(1) Model Variations. Variations among models are described in text.

(2) Time and Technique. The time required for this calibration is approximately 8 hours, using the dc and physical technique.

b. Calibration Description.

TI parameters and performance specifications which pertain to this calibration are listed in table 4.

Table 4. Calibration Description.

Test Instrument	Performance Specifications.
62C (7912276-1)	Range: -38 to +2 °C Accuracy: ±0.1 °C
63C (7912276-2)	Range: -8 to +32 °C Accuracy: ±0.1 °C
64C (7912276-3)	Range: 25 to 55 °C Accuracy: ±0.1 °C
65C (7912276-4)	Range: 50 to 80 °C Accuracy: ±0.1 °C
66C (7912276-5)	Range: 75 to 105 °C Accuracy: ±0.1 °C
67C (7912276-6)	Range: 95 to 155 °C Accuracy: ±0.2 °C
68C (7912276-7)	Range: 145 to 205 °C Accuracy: ±0.2 °C
69C (7912276-8)	Range: 195 to 305 °C Accuracy: ±0.5 °C
15-142D	Range: 122 to 176 °F Accuracy: ±0.2 °F
15-142F	Range: 205 to 311 °F Accuracy: ±0.5 °F
ASTM 50F and 7910469	Range: 54 to 101 °F Accuracy: ±0.1 °F
ASTM 80-182 (80-211-22)	[1]

[1]See note after table 5.

NOTE

The accuracies specified in table 1 are the accuracies of the thermometers without scale corrections at the time of procurement. They do not require verification except for initial acceptance.

c. Equipment Required

Table 5 identifies the specific equipment used in this calibration procedure. This equipment is issued with the secondary reference calibration standards set and is to be used in performing this procedure. Alternate items may be used by the calibrating activity when the equipment listed in table 5 is not available. The items selected must be verified to perform satisfactorily prior to use and must bear evidence of current calibration. The equipment must meet or exceed the minimum use specifications listed in table 5. The accuracies listed in table 5 provide a four-to-one accuracy ratio between the standard and TI. Where the four-to-one ratio cannot be met, and actual accuracy of the equipment selected is shown in parenthesis.

d. Accessories Required

The accessories listed in table 6 are issued with the secondary reference calibration standards set and are to be used in this calibration procedure. When necessary, these items may be substituted by equivalent items unless specifically prohibited.

Table 5. Minimum Specifications of Equipment Required.

Item	Common Name	Minimum Use Specifications.	Manufacturer, Model, and Part Number.
A1	DITIGAL VOLTMETER.	Range: 0 to 20 mv Accuracy: ±0.1 %	Dana, Model 5703-S-2127 (7912606)
A2	DC CURRENT SHUNT.	Range: 0 to 2 ma Accuracy: 0.1 %	Rubicon, Model 2759 (7909012)
A3	NULL DETECTOR	Range: 0 to 20 mv	John Fluke, Model 845AB (845AB)
A4	POWER SUPPLY	Range: 2 ma	NJE, Model CS36CR30 (7907346-2)
A5	RESISTANCE BRIDGE.	Range: -30 to +250 ° C Accuracy: 0.01 ° C	Biddle-Gray, Model 60-1003 (7907127)
A6	RESISTANCE THERMOMETER.	Range: -30 ° to +260 ° C Accuracy: ±0.003 ° C	Rosemont, Model 162C (MIS-10328)
A7	TEMPERATURE BATH.	Range: -30 ° C to ambient	Hallikainen, Model 1282A52 (7907735)
A8	TEMPERATURE BATH.	Range: Ambient to 250 ° C	Hallikainen, Model 1128C52 (7907733)
A9	TEMPERATURE STANDARD.	Range: 0.0100 ° C Accuracy: ±0.0005 ° C	Transonic, Model 130C (7910388)

Table 6. Accessories Required.

Item	Common Name	Description and Part Number
B1	ADAPTER[1]	Single banana jack to spade (black) (7907502-2).
B2	ADAPTER[1]	Single banana jack to spade (red) (7907502-1).
B3	LEAD[1]	Single banana plug terminations (black) (7907492).
B4	LEAD[2]	Single banana plug terminations (red) (7907491).
B5	THERMOMETER CALIBRATION KIT.	7911944

[1] Two required.
[2] Three required.

e. Preliminary Instructions

(1) The instructions outlined in this section are preparatory to the calibration process. Personnel should become familiar with the entire procedure before beginning the calibration.

(2) Items of equipment used in this procedure are referenced within the text by common name and item identification number as listed in tables 5 and 6. For the identification of equipment referenced by items number prefixed with A, see table 5, and for prefix B, see table 6.

f. Equipment Setup

(1) Remove TI from protective case.

(2) Inspect TI bulb and stem for foreign matter and evidence of deterioration.

(3) Hold TI in vertical position and verify that bulb and column are free from gas bubbles and that stem is free from globules of liquid. If not, perform (1), (2), or (3) below as applicable.

(a) Eliminate gas bubbles in TI bulb by cooling with dry ice or equivalent coolant until liquid is drawn into bulb. Tap TI gently against pad of paper. Bubbles should rise to surface and disperse. Hold TI upright while allowing it to return to room temperature.

(b) Eliminate gas bubble from stem of TI with expansion chambers by slowly and carefully heating bulb until bubbles are joined. Carefully tap TI against pad of paper or against palm of hand.

CAUTION

To avoid damage to TI, exercise extreme care when applying heat. Do not heat with open flame.

(c) Eliminate globules of liquid inside TI stem by carefully and slowly heating TI bulb until liquid column merges with globules.

NOTE: If globules tend to unite and reappear after bulb cools, obstructions or oxidation of mercury may by present, and TI must be rejected.

(4) Prepare temperature standard (A9) for proper ice mantle formation.

g. Zero Point Temperature Check

(1) Performance Check

NOTE: Unless otherwise specified, verify the results of each test and take corrective action whenever the test requirement is not met before continuing with the calibration.

(a) Insert TI (model 62C) into temperature standard (A9) so that top of mercury column is below top of mantle.

NOTE: If necessary, an ice bath may be substituted for temperature standard.

(b) After at least 3 minutes, record TI temperature indication.

NOTE: To minimize emergent stem error, observe indication through cell just above ice mantle.

(c) Repeat (a) and (b) above two times at 5-minute intervals.

(d) Average the three indications recorded in (b) above. If average indication is not within ˚±0.05 degree centigrade, perform (2) below.

(e) Repeat technique of (a) through (d) above for remaining TI's listed in table 7. Average indication will be within limits specified.

(2) Adjustments

(a) If TI indication exceeds the tolerance limitation (rejection tolerance) listed in table 7, the TI will be rejected.
(b) If the TI indication exceeds the correction tolerance listed in table 7, but does not exceed the rejection tolerance, prepare a correction chart, specifying the scale correction.

Table 7. Zero Point Check.

Test Instrument		Scale Correction Tolerance (°C).	Rejection Tolerance (°C).
Model No.	Army Part No.		
62C	7912276-1	±0.05	±0.3
63C	7912276-2	±0.5	±0.3
64C	7912276-3	±0.05	±0.3
65C	7912276-4	±0.05	±0.3
66C	7912276-5	±0.05	±0.3
67C	7912276-6	±0.1	±0.4
68C	7912276-7	±0.1	±0.5
69C	7912276-8	±0.3	±2.0
15-142D		±0.05 (0.90 °F)	±0.3 (0.54 °F)
15-142F		±0.1 (0.18 °F)	±0.4 (0.72 °F)
ASTM 80-182			
	7913469	±0.028 (±0.05°F)	±0.22 (±0.4°F)

'See note after table 8.

h. Temperature Calibration

(1) Performance Check

NOTE: This entire calibration procedure will be used to calibrate all TI's until a 3-year history of stability is established. The TI's will then be given only the zero point temperature check, paragraph 7g above, after stability criteria have been satisfied.

(a) Connect equipment as shown in figure 23.
(b) Prepare temperature standard (A9).
(c) Insert resistance thermometer (A6) into temperature standard.
(d) After at least 3 minutes, operate resistance bridge (A5) at 2 milliamperes as indicated by current measuring system, and record bridge indication.

NOTE: Current measuring system consists of power supply (A4), dc current shunt (A2), and digital voltmeter (A1).

(e) Repeat (d) above three times.
(f) Determine average of indications recorded in (d) above.
(g) Refer to calibration table for resistance thermometer and determine by interpolation the table resistance ratio value for 0.01 C.
(h) Divide the resistance obtained in (f) above by the resistance ratio for 0.01˚¸C. Record this value as R˚¸.

(i) When calibrating thermometer set 7910479, select TI model 62C as first item to be calibrated.
(j) Adjust temperature bath (A7) to approximately -30˚¸C.
(k) Lower resistance thermometer into temperature bath along with TI selected in (i) above.
(l) Allow sufficient time for TI and resistance thermometer to stabilize, and record TI temperature and temperature of resistance thermometer

NOTE: Temperature of resistance thermometer is determined by resistance bridge and resistance ratio table supplied with resistance thermometer.

(m) Compute TI emergent stem correction as follows:

Stem correction - Kn (T - t).
K = 0.00016 for Celsius thermometers
= 0.00009 for Fahrenheit thermometers
T = TI indication in ˚¸C
n = Number of degrees on TI scale from top of liquid level to temperature indication.
t = Mean temperature of emergent TI stem.

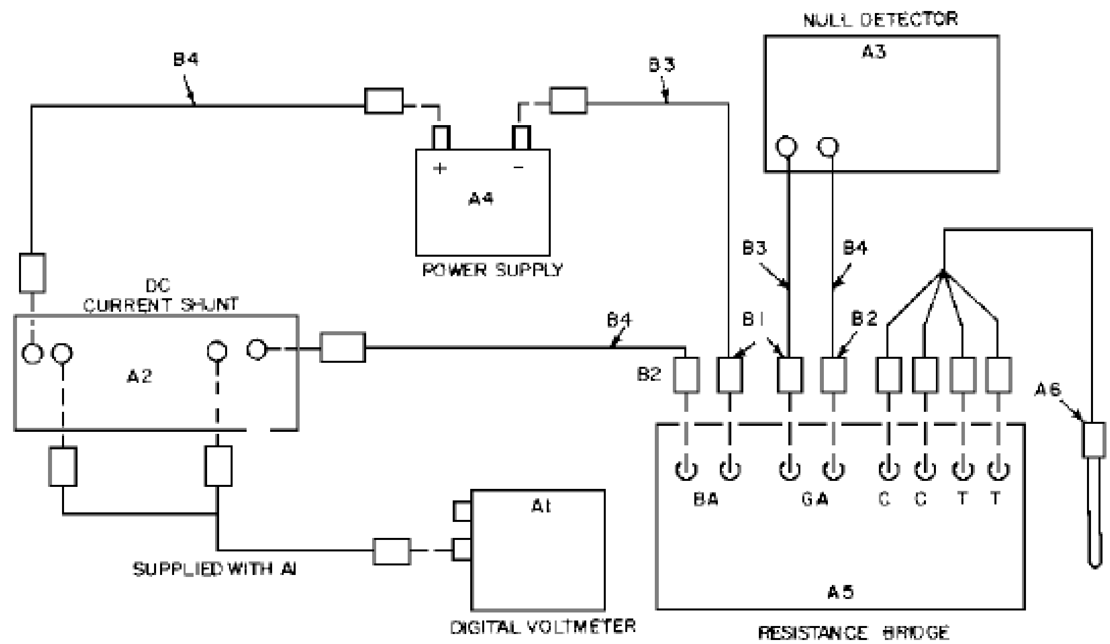


Figure 23. Temperature Accuracy-equipment setup.

(n) Apply stem correction determined in (m) above to TI temperature recorded in (1) above, and record result as corrected temperature.
(o) Compare TI corrected temperature recorded in (m) above with temperature of resistance thermometer recorded in (1) above. Record deviation of TI from resistance thermometer.
(p) Repeat (k) above three times at 5-minute intervals.
(q) Determine average of deviations recorded in (o) above. If average deviation is not within ˚±0.05 degree, perform b below.

(r) Repeat technique of (i) through (q) above for each TI model at temperature-bath temperatures listed in table 8. If average allowable deviations are not within limits specified, perform b below.

(2) Adjustments

(a) If TI is out of tolerance according to average allowable deviation column of table 8, but within tolerance according to rejection tolerance column, prepare calibration curve, using values from paragraph 7 b (2) and a above and attach to TI.

(b) If TI is out of tolerance according to both average allowable deviation and rejection tolerance columns of table 8, TI must be rejected.

i. FINAL PROCEDURE

(1) Disconnect all equipment.

(2) Rinse and dry TI and standards and return them to their protective cases.

Table 8. Temperature Calibration.

Test Instrument Model No.	Temperature-Bath Temperature (° C).	Average Allowable Deviation (° C).	Rejection Tolerance (° C).
62C	-30 -20 -10	±0.05	±0.3
63C	10 20 30	±0.05	±0.3
64C	30 40 50	±0.05	±0.3
65C	55 65 75	±0.05	±0.3
66C	80 90 100	±0.05	±0.3
67C	105 125 150	±0.10	±0.4
68C	150 170 200	±0.10	±0.5
69C	210 230 250	±0.3	±2.0
15-142D	51.67 (125 °F) 65.16 (150 °F) 79.45 (175 °F)	±0.05 (±0.09 °F)	±0.3 (±0.5 °F)
15-142F	98.89 (210 °F) 121.11 (250 °F) 148.89 (300 °F)	±0.10 (±0.18 °F)	±0.4 (±0.72 °F)
ATSM 50F and 7913469	21.1 (70 °F) 26.7 (80 °F) 32.2 (90 °F)	±0.028 (±0.05 °F)	±0.22 (±0.4 °F)
ATSM 80-182 (80-211-22)	[1] [2]	[1]	[1]

[1] This thermometer set may be calibrated to the same accuracy as thermometer set 7930479 using same technique. This set is graduated to the Fahrenheit scale. Therefore, conversion to the equivalent Celsius value of this table is necessary. The temperature conversion formulas below may be used:

°F = °C X 9/5 + 32

°C = 5/9 X (°F — 32)

[2] Procedure limitation. ASTM 70F is beyond the range of temperature bath (A8).

(3) In accordance with TM 38-750, annotate and affix DA Label 80 (U.S. Army Calibration System). When the TI cannot be adjusted within tolerance, annotate and affix DA Form 2417 (Unserviceable or Limited Use) tag.

9. Conclusion:

In this lesson we have discussed the calibration standards used to calibrate temperature sensing devises at the transfer and secondary reference level, it is or should be apparent that much more material could be covered. However, the state of the art of thermometery is constantly changing. New techniques and standards are being developed to further simplify and maintain accuracies during the calibration process.

A thorough knowledge of the fundamentals of thermometry and the development of manipulative skills using the prescribed standards will greatly increase your value to your unit and the U.S. Army.

EXERCISES FOR LESSON 2

1. The triple point of water is also called the equaphase of water, because water

   A. becomes a solid at 30øF.
   B. coexists as liquid, solid and gas (vapor) at 0.01000øC.
   C. coexists with other elements.
   D. coexists as liquid and a solid at various temperatures, above 40øC.

2. What must be done to prevent the formation of gas pockets in the thermometer well of the equaphase cell?

   A. turn the cell upside down
   B. por 3 cc of water into the well
   C. shake the cell gently
   D. use a vacuum pump to draw off any gas

3. Dry ice should be ground to what size?

   A. 1" to 3"
   B. any size that will fit the well
   C. melt the ice first
   D. fine snow to 1/16" diameter

4. When testing (by comparison) two equiphase cells which of the following is true.

   A. No temperature difference will be noted if both cells are free of impurities.
   B. The cell with the lower temperature will be accepted.
   C. If both cells have the same temperature reading, both cells will be disguarded.

5. When using the equiphase cell, thermometer leads should be tempered

   A. to prevent the leads from becoming to brittle.
   B. to prevent heat conduction through the leads down into the well.
   C. to prevent the leads from bending.
   D. to prevent the well from freezing.

6. What must be done to preserve an ice mantle for a day or longer?

A. Place the glass cell in a sub-zero freezer.
B. Pack the cell in dry ice.
C. Place the jacket containing the cell in a freezer.
D. The cell may be removed from the jacket and packed in ice.

7. The Model RCSI-SP Ice-Point Calibration Standard will maintain the ice point cell at

A. 0ø centigrade.
B. .0100ø centigrade.
C. .001000ø centigrade.
D. .000100ø centigrade.

8. How far (in depth) must a thermometer be inserted into the well of the ice point standard?

A. to the depth necessary to get a reading
B. completely to the bottom of the well
C. half way
D. place only the bulb of the thermometer into the well

9. What is used in the cold bath as the bath medium?

A. A 50% solution of water and alcohol.
B. A 60/40 solution of water and a silicone based oil.
C. A 60% by volume solution of ethylene glycol in water.
D. 100% antifreeze.

10. What are the secondary reference temperature standards?

A. Equiphase cell and hot bath
B. Ice point standard and equiphase cell
C. Thermocouple, mercury in glass thermometer and the resistance thermometer
D. Thermocouple, mercury in glass thermometer equiphase cell and the cold bath

11. What is done to eliminate gas bubbles in mercury and glass thermometers with expansion chambers?

A. Heat thermometer bulb with open flame until bubbles are joined. Carefully tap thermometer against pad of paper or against palm of hand.
B. Heat bulb slowly and carefully until bubbles are joined. Carefully tap thermometer against pad of paper or against palm of hand.

C. Perform the calibration procedure and make appropriate allowances for any gas bubbles.

D. Discard the thermometer.

12. What is the range of the secondary reference thermocouple?

A. -10øC to 1,760øC
B. -5øC to 1,765øC
C. 0øC to 1,768øC
D. 0øC to 1,770øC

13. What is the maximum range of the Instrulab 4100 when in the hundredth (0.01) degree position?

A. 100øC or 232øF
B. 100øC or 300øF
C. 200øC or 350øF
D. 250ø or 375ø F

14. When using the Instrulab on battery power alone, how often must the battery be checked?

A. Before each important measurement
B. Before the instrument is put into operation
C. After a measurement is taken
D. Before and after each important measurement

15. What are the three regulated outputs from the inverter circuit of the Instrulab 4100?

A. Positive 10 volts, negative 10 volts, positive 4.5 volts
B. Positive 12 volts, negative 10 volts, positive 4.5 volts
C. Positive 15 volts, negative 15 volts, positive 5 volts
D. Positive 20 volts, negative 20 volts, positive 15 volts

APPROVED SOLUTION

LESSON 1. THERMOMETRY

1. A Para 1
2. C Para 2
3. C Para 4
4. C Para 4
5. B Para 5
6. C Para 7
7. D Para 10
8. A Para 10
9. B Para 9
10. D Para 9

LESSON 2. CALIBRATION & USE OF TEMPERATURE STANDARDS

1. B Para 1
2. C Para 2F (1)(b)
3. D Para 2F (1)(b)
4. A Para 2
5. B Para 2 (c)(6)
6. D Para 2 (c)(4)
7. A Para 3c
11. B Para 7F (3)
12. C Para 5
13. A Para 6e
14. D Para 6e
15. C Para 6g (9)

8. B Para 3e
9. B Para 4
10. C Para 4