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ABSTRACT

This module on heat storage is one of six in a series intended for use as supplements to currently available materials on solar energy and energy conservation. Together with the recommended texts and references (sources are identified), these modules provide an effective introduction to energy conservation and solar energy technologies. The module is divided into these sections: (1) set of objectives; (2) programed instructional material, consisting of short readings describing ideas and techniques one step at a time, and a question or problem on each reading; (3) review questions and answers at intervals; and (4) posttest. Objectives for this module are for the student to be able to list and describe basic methods of heat storage and compute the amount of heat stored in a substance and the volume required to store the heat. (YLB)

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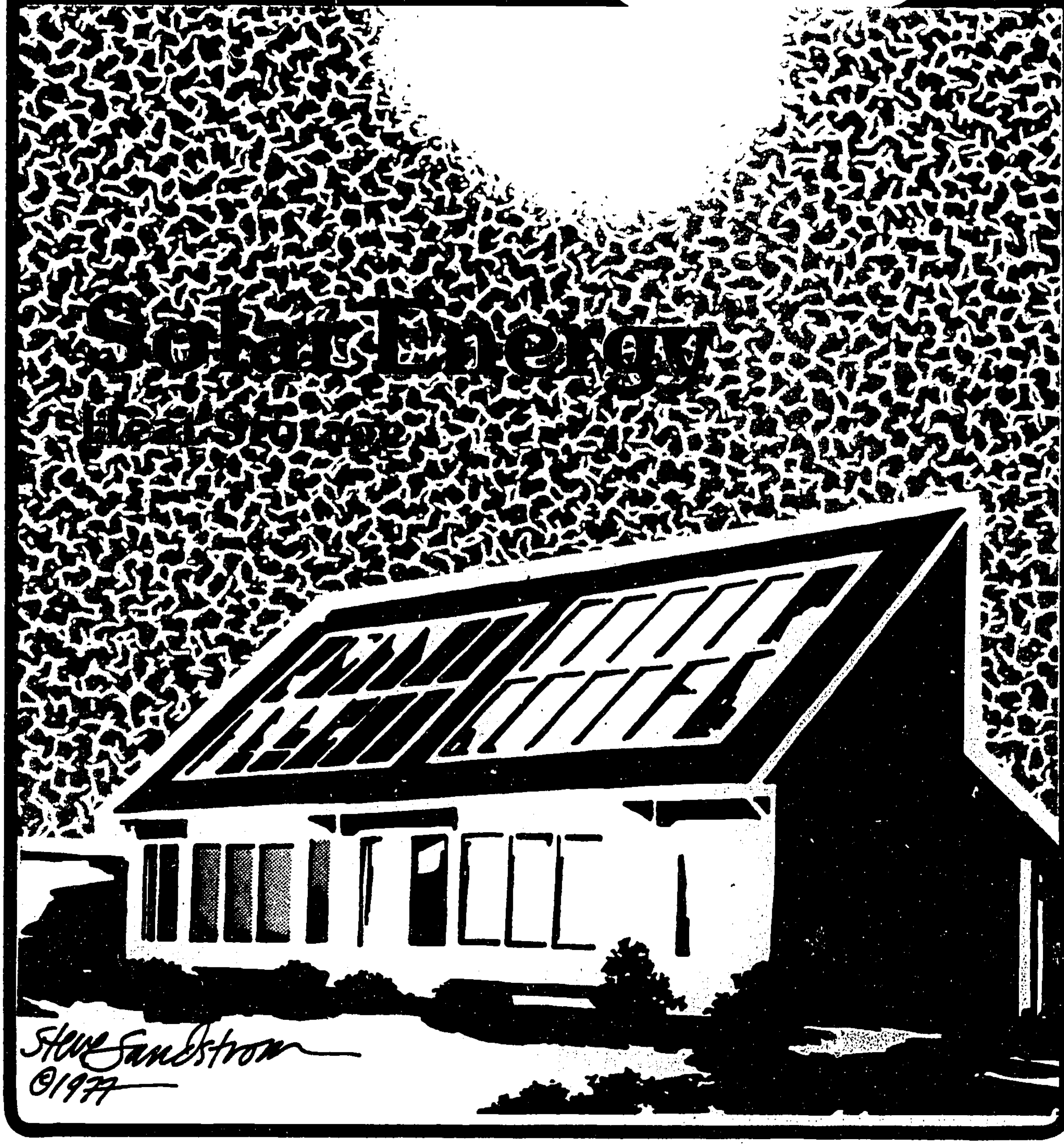
INDIVIDUALIZED LEARNING SYSTEMS

Solar Energy

Heat Storage



INSTRUCTIONAL LEARNING SYSTEMS

Solar Energy

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Introduction

These modules are intended to be used as supplements to currently available materials on solar energy and energy conservation. The two best available texts are

Leckie, Masters, Whitehouse and Young; Other Homes and Garbage, Sierra Club Books, 1975

and

Anderson, The Solar Home Book, Cheshire Books, 1975.

There are several reference works that would also be very useful to have on hand. The three most useful ones are

ASHRAE Guide and Data Book, Handbook of Fundamentals, American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1977.

U.S. Department of Commerce, Climatic Atlas of the United States, Environmental Data Service, Reprinted by the National Oceanic and Atmospheric Administration, 1974.

U.S. Department of Commerce, Monthly Normal of Temperature, Precipitation and Heating and Cooling Degree-Days (1941-1970) National Oceanic and Atmospheric Administration, Climatography of the United States (by state).

The last two references can be obtained from the National Climatic Center, Environmental Data Service, Federal Building, Asheville, NC 28801. The most important data to have on hand are the per cent possible sunshine and heating degree-day records for locations in Oregon. They're available in the last two references. Some data are also available in the two texts and the modules themselves.

The modules are designed to simplify and supplement the treatment of some of the subjects discussed in the texts and references. In combination, the modules, texts, and references provide an effective introduction to energy conservation and solar energy technologies.

The technique you'll use to learn the skills presented in this module is called programmed instruction. It's a technique which we think will enable you to learn these new skills quickly and easily.

The module is divided into several sections:

1. A list of objectives, which tells you what you should expect to learn from this module.
2. Programmed instructional material which we'll describe later on in this introduction.
3. A post-test, which will help you find out what you were able to learn by using the module.
4. A student evaluation form which you can use to tell us what you liked and disliked about the module, so we can make it better for students who use it later on.

The programmed part of the module consists of short readings which show you the ideas and techniques you need a step at a time. Most are followed by a question or problem which gives you a chance to review what you just read. Depending on your answer to the question or problem, you'll be guided to another short reading which will either help you review a little more, or introduce you to a new idea or technique. Each short reading is called a <u>frame</u>.

To get the most out of the programmed part, you need to follow the directions exactly. Resist any temptations to skip around, and respond in the best way you can to the question in each frame before moving on to the frame you're told to read next.

It'll help to have pencil, paper, and a pocket calculator handy for some of the computations you're asked to do.

Don't forget about your instructor. You don't have to do it all by yourself. Ask for help with any part of the module that you can't get through by yourself. Good luck!

OBJECTIVES

Overall Objective 1

The student will be able to list and describe the basic methods of heat storage.

Sub-objectives

The student will be able to:

A. Give a definition of heat.
B. Give a definition of temperature, and relate it to the definition of heat.
C. Give a definition of sensible heat capacity and relate it to the definitions of heat and temperature.
D. Give a definition of latent heat capacity and relate it to the definitions of temperature and heat.

Overall Objective 2

The student will be able to compute the amount of heat stored in a substance and the volume required to store the heat.

Sub-objectives

The student will be able to:

A. Describe the bases of both of the temperature scales now commonly used, and convert temperatures from one scale to the other.
B. Compute the amount of available sensible heat contained in a material.
C. Compute the amount of latent heat stored in a material.
D. Compute the volume of a material required to store a given amount of heat.

1. Heat storage is a very useful way to reduce energy use in buildings. Solar systems must use stored heat to provide heat when the sun isn't shining.

Even in buildings that aren't solar heated and don't get their hot water from solar collectors, heat storage can be used. Solar heat from ordinary windows can be stored in rock or concrete floors and walls, as can heat from stoves, fireplaces, and other heat-producing appliances.

The learning program you're about to begin will help you learn how heat can be stored, and how to compute the amount of heat stored in various ways and in different materials.

Two sources of supplementary information on heat storage and energy conservation are:

Leckie, Masters, Whitehouse, and Young: Other Homes and Garbage, Sierra Club Books, 1975, Chapter 4., pp. 123-127.

Anderson, The Solar Home Book, Cheshire Books, 1976.

When you touch something that's hot, it transfers heat to your body. But, what's heat?

Heat is a special kind of motion. It's the tiny, disorganized motion of the atoms and molecules which make up everything we see in the world. Those atoms and molecules are always moving around, in all objects, even in hard, solid objects like tables and chairs.

Solid objects don't fall apart because their atoms and molecules are held together by electrical forces, but the forces aren't strong enough to keep them completely motionless. It's as if they're connected to each other by springs which allow them to bounce around all over the place without actually flying apart. The bouncing around is the motion we call heat. You usually can't see heat motion, because the individual atoms or molecules are way too small, and they only move a short distance in any one direction before bounding off in another direction.

Organized motion of atoms and molecules does not make heat. When the atoms and molecules are all moving in the same direction at once, the entire object that contains them is moving, like when you're driving in a car. It's the disorganized bouncing around of individual atoms and molecules that makes heat. That happens whether or not an object is standing still.

Answer this true or false question:

Heat is the organized motion of the molecules and atoms in an object.

A. True, go on to frame 2.

B. False, go on to frame 3.

---

2. That's not right. Organized motion of atoms and molecules is what's happening when an entire object is moving. Review frame 1 to make sure you understand the difference between organized motion of atoms and molecules and heat.

---

3. Right. Heat is the disorganized motion of atoms and molecules in objects.

Now, answer this one:

A chair and a moving car both contain heat energy.

A. True, go on to frame 4.

B. False, go to frame 6.

---

4. Right. Go on to frame 5.

---

5. The atoms and molecules of an object bounce around whether the whole object is moving or not. Heat is a form of energy. Everything contains some heat energy, because its atoms or molecules are always bouncing around inside it no matter how cold or hot it feels. If an object feels hot, its atoms and molecules are bouncing around faster than the atoms and molecules in your body. If it feels cool or cold, they're just bouncing around slower.

The hotter an object gets, the faster its atoms and molecules bounce around. Sometimes, they can even get moving fast enough to break away from each other. You can see that happen when you boil water. It starts to bubble, and steam comes out when some of the molecules get moving fast enough to break free from the rest.

Answer this question:

Hot water is hotter than ice because

A. Ice doesn't contain any heat. Go to frame 7.

B. The water molecules are bouncing around faster than the ice molecules. Go to frame 8.

---

6. No, that's not right. All objects contain heat energy, whether they're moving or not. You've almost got the idea. Go back and reread frame 1 to make sure you understand.

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7. Sorry, <u>all</u> objects, whether they <u>feel</u> cold or not, contain heat. Reread frame 5 and try again.

---

8. Right. Go to frame 9.

---

9. Heat energy gets <u>transferred</u> when atoms or molecules that are bouncing around hit other atoms or molecules that are bouncing around slower. The faster bouncers speed up the slower ones, making them <u>hotter</u>; and in the process, the faster ones slow down and get a little colder. The faster atoms or molecules transfer some of their heat energy to the colder ones by hitting them and speeding them up.

   We say the faster molecules or atoms are at a <u>higher temperature</u> than the slower ones. In other words, the <u>temperature</u> of an object or a substance like air or water is a measure of how fast its molecules or atoms are moving. Heat energy always gets transferred from the higher temperature object or substance to the colder one if they're allowed to come in contact with each other in some way.

   Now answer this question:

   Heat is transferred from a higher temperature object to a lower temperature object because

   A. The higher temperature object contains more heat energy. Go to frame 10.

   B. The molecules or atoms of the higher temperature object are moving faster than those of the lower temperature object. Go to frame 11.

---

10. No. It's the <u>speed</u> of the motion of the molecules or atoms of the object or substance which determines its temperature. The total amount of heat energy in a substance doesn't have to be large for it to transfer heat to a cooler substance. A <u>small number</u> of very fast moving atoms or molecules whose <u>total</u> heat energy is small can still transfer heat to a much larger number of

slower moving molecules which contain a lot of heat energy, but at a lower temperature. Go back and reread frame 8, and answer the question again.

---

11. O.K. You can see now that the total amount of heat energy in a large object can be great, and it still may not be able to transfer heat to a smaller object which has less total heat energy, but is at a higher temperature. Of the two objects, the one whose molecules or atoms are moving faster is the one that is at a higher temperature. It will transfer heat to the other one regardless of their relative sizes or the total amount of heat energy each contains. Go on to frame 12.

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12. The temperature of a substance is measured by determining the average speed of the bouncing motion of its atoms or molecules. A thermometer is a device for measuring the average speed of the bouncing motion of atoms or molecules. The most common kind of thermometer, the mercury thermometer, measures the speed by letting its mercury atoms get speeded up or slowed down to the same average speed as those of the substance it's touching. When its molecules speed up, they cause the liquid mercury to expand, because their motions take up more space. When they slow down, the liquid mercury contracts. The result is that the length of a column of mercury in a mercury thermometer tells you how fast the mercury molecules are moving. That's a measure of their temperature and the temperature of the substance the thermometer is touching. Other kinds of thermometers use different ways of measuring molecular speed.

    Now, answer this question:

    A mercury thermometer is put into a glass of water and the mercury column goes down (gets shorter). What happened?

    A. The mercury was at a lower temperature than the water, and the water transferred heat to it. Go to frame 13.
    B. The mercury was at a higher temperature than the water, and it transferred heat to the water. Go to frame 14.
    C. Neither A nor B. Go to frame 15.

---

13. Nope. Reread frame 10 and choose another answer.

---

14. That's right. Before the thermometer was placed in the water, the mercury atoms were moving faster than the water molecules. Atoms in the glass surrounding the mercury column in the thermometer were also moving faster than the water molecules. In fact, they were moving just as fast as the mercury atoms. When the thermometer went into the water, the fast moving glass atoms slowed down as they hit the slower moving water molecules. When the glass atoms slowed down, the mercury atoms started slowing down too, as they hit slower moving glass atoms. After a while, the mercury atoms, glass atoms, and water molecules all were moving at the same average speed. That's what happens when two objects at different temperatures come in contact. The atoms or molecules of the hotter one hit those of the colder one and speed them up. In the process, the hotter object transfers heat to the colder one, and the atoms or molecules of the two objects wind up moving at the same average speed. The two objects are then at the same temperature. Go on to frame 16.

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15. Looks like you're a bit confused. You still may not understand the relationship between the speed of the motion of atoms and molecules, their temperature and how heat is transferred. Try going back to frame 9, and work your way through the frames between it and this one.

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16. You probably already know that two different temperature scales are used to describe temperatures: the Fahrenheit scale and the centigrade, or Celsius scale. On the Fahrenheit scale, the temperature of freezing water is 32 degrees, and the temperature of boiling water is 212 degrees. On the Celsius scale, the temperature of freezing water is 0 degrees, and the temperature of boiling water is 100 degrees. ^{o}F. stands for "degrees Fahrenheit" and ^{o}C. stands for "degrees Celsius". ^{o}F. and ^{o}C. are called the <u>units</u> of measurement of temperature.

You can see with a bit of subtraction that the <u>temperature difference</u> between boiling and freezing water can be described <u>either</u> as 100 ^{o}C. or 180 ^{o}F. The shorthand for temperature difference is ΔT. The Δ is a Greek letter delta, and stands for difference, or change. The T stands for temperature.

To describe the temperature difference between freezing and boiling water, you can either write

$\Delta T = 100\ ^{o}C. - 0\ ^{o}C. = 100\ ^{o}C.$

or $\Delta T = 212\ ^{o}F. - 32\ ^{o}F. = 180\ ^{o}F.$

Describe the temperature difference between the temperatures given below and freezing water. Use the same temperature scale as the one used to describe the temperature given, and the shorthand you just learned. Check your answers in frame 17.

A. $T = 72\ ^{o}F.$ $\Delta T =$

B. $T = 10\ ^{o}C.$ $\Delta T =$

C. $T = 35\ ^{o}C.$ $\Delta T =$

D. $T = 108\ ^{o}F.$ $\Delta T =$

---

17. You should have gotten

A. $\Delta T = 40\ ^{o}F.$

B. $\Delta T = 10\ ^{o}C.$

C. $\Delta T = 35\ ^{o}C.$

D. $\Delta T = 76\ ^{o}F.$

---

18. To find T, all you had to do was subtract the temperature of freezing water <u>on the temperature scale used to describe the temperature given</u>.

$\Delta T = 72\ ^{o}F. - 32\ ^{o}F. = 40\ ^{o}F.$

$\Delta T = 10\ ^{o}C. - 0\ ^{o}C. = 10\ ^{o}C.$

$\Delta T = 35\ ^{o}C. - 0\ ^{o}C. = 35\ ^{o}C.$

$\Delta T = 108\ ^{o}F. - 32\ ^{o}F. = 76\ ^{o}F.$

Try these, and check your answers in frame 19.

$T = 98\ ^{o}F.$ $\Delta T =$

$T = 70\ ^{o}C.$ $\Delta T =$

$T = 57\ ^{o}F.$ $\Delta T =$

$T = 72\ ^{o}C.$ $\Delta T =$

---

19. You should have gotten

$T = 98\ ^{o}F. - 32\ ^{o}F. = 66\ ^{o}F.$

$T = 70\ ^{o}C. - 0\ ^{o}C. = 70\ ^{o}C.$

$T = 57\ ^{o}F. - 32\ ^{o}F. = 25\ ^{o}F.$ 12

$T = 72\ ^{o}C. - 0\ ^{o}C. = 72\ ^{o}C.$

If you missed any of these, go back through frames 16, 17, and 18 again until you're sure you understand how to find ΔT in $^{o}F.$ and $^{o}C.$ If you didn't, go on to frame 20.

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20. The next thing to learn is how to convert a ΔT from $^{o}C.$ to $^{o}F.$ It's easy if you use a little more shorthand. You already know that the temperature of boiling water can be described <u>either</u> as 100 $^{o}C.$ or 212 $^{o}F.$ So, the temperature difference between boiling and freezing water can be written either

$\Delta T = 100\ ^{o}C. - 0\ ^{o}C. = 100\ ^{o}C.$

or $\Delta T = 212\ ^{o}F. - 32\ ^{o}F. = 180\ ^{o}F.$

A temperature difference a hundred times smaller than the difference between boiling and freezing water can be described as

$\Delta T = \frac{100}{100}\ ^{o}C. = 1\ ^{o}C.$

or $\Delta T = \frac{180}{100}\ ^{o}F. = 1.8\ ^{o}F.$

So, for every degree in a $^{o}C.$ description of a temperature difference, there are 1.8 degrees in the $^{o}F.$ description of the same temperature difference. That fact can be condensed into a symbol called a <u>unit conversion factor</u>.

The unit conversion factor between $^{o}F.$ and $^{o}C.$ is written

$(1.8\ ^{o}F./^{o}C.)$

and is translated "1.8 $^{o}F.$ per $^{o}C.$" or "there are 1.8 $^{o}F.$ for each $^{o}C.$".

To use the conversion factor to change or <u>convert</u> a description of ΔT from $^{o}C.$ to $^{o}F.$, you just multiply the number of $^{o}C.$ by the conversion factor as if the 1.8 $^{o}F./^{o}C.$ were a fraction. Here's an example:

$\Delta T = 50\ ^{o}C.$

$\Delta T = (1.8\ ^{o}F./\cancel{^{o}C.})\ (50\ \cancel{^{o}C.})$

$\Delta T = (1.8\ ^{o}F.)\ 50$

$\Delta T = 90\ ^{o}F.$

You can see that if you treat the $^{o}C.$ in $(1.8\ ^{o}F./^{o}C.)$ as if it were a number in the denominator of a fraction, it <u>cancels</u> the $^{o}C.$ in 50 $^{o}C.$, and you're left with ΔT described in $^{o}F.$ after you multiply the 50 by the 1.8. It's that easy. Just pretend the two $^{o}C.$ symbols are numbers, and that 1.8 $^{o}F./^{o}C.$ is a fraction, then cancel and multiply. Try these, and check your answers in frame 21.

A. $\Delta T = 30\ ^{o}C.$

B. $\Delta T = 55\ ^{o}C.$

C. $\Delta T = 70\ ^{o}C.$

---

21. You should have gotten

A. $\Delta T = 54\ ^{o}F.$

B. $\Delta T = 99\ ^{o}F.$

C. $\Delta T = 126\ ^{o}F.$

If you got them all, go to frame 24. If you missed any, go to frame 22.

---

22. O.K. Let's go over it again. Pretend the conversion factor ($1.8\ ^{o}F./^{o}C.$) is a fraction. Multiply by it. Treat the two $^{o}C.$ symbols like numbers and let them cancel each other out. You're left with $1.8\ ^{o}F.$ times a plain number. Multiply. That's the $^{o}F.$ description of ΔT. Here's another example:

$\Delta T = 10\ ^{o}C.$

$\Delta T = (1.8\ ^{o}F./\cancel{^{o}C.})\ 10\ \cancel{^{o}C.}$

$\Delta T = (1.8\ ^{o}F.)\ 10$

$\Delta T = 18\ ^{o}F.$

Try these, and check your answers in frame 23.

A. $\Delta T = 15\ ^{o}C.$

B. $\Delta T = 25\ ^{o}C.$

C. $\Delta T = 80\ ^{o}C.$

23. You should have:

A. $\Delta T = 27\ ^{o}F.$

B. $\Delta T = 45\ ^{o}F.$

C. $\Delta T = 144\ ^{o}F.$

If you got all of these, go on to frame 24. If not, go back to frame 20, and try again.

---

24. To convert a description of a ΔT from $^{o}F.$ to $^{o}C.$, you just reverse, or <u>invert</u> the conversion factor from 1.8 $^{o}F./^{o}C.$ to $^{o}C./1.8\ ^{o}F.$, multiply and cancel like before:

$\Delta T = 72\ ^{o}F.$

$\Delta T = (^{o}C./1.8\ \cancel{^{o}F.})\ 72\ \cancel{^{o}F.}$

$\Delta T = \dfrac{72\ ^{o}C.}{1.8}$

$\Delta T = 40\ ^{o}C.$

Notice that this time the 1.8 is in the denominator of the "fraction" ($^{o}C./1.8\ ^{o}F.$), and you <u>divide</u> by it instead of multiplying by it. That automatically adjusts for the fact that 1 $^{o}F.$ is smaller than 1 $^{o}C.$, and changes the description of ΔT from 72 $^{o}F.$ into 40 $^{o}C.$, as it should You can easily remember to divide by 1.8, because it's the denominator of the "fraction".

Try these, and check your answers in frame 25.

A. $\Delta T = 144\ ^{o}F.$

B. $\Delta T = 27\ ^{o}F.$

C. $\Delta T = 81\ ^{o}F.$

25. You should have gotten

A. $\Delta T = 80\ ^{o}C.$

B. $\Delta T = 15\ ^{o}C.$

C. $\Delta T = 45\ ^{o}C.$

If you did, go to frame 26. If not, go to frame 27.

---

26. O.K. You've learned how to convert temperature difference descriptions from $^{o}C.$ to $^{o}F.$, and back. The next step is learning to convert individual temperatures from $^{o}C.$ to $^{o}F.$ and back again. To do that, you take the temperature of freezing water as your starting point. In $^{o}C.$, it's $0\ ^{o}C.$, and in $^{o}F.$, it's $32\ ^{o}F.$

Suppose you're starting with $^{o}F.$, and want to convert to $^{o}C.$ First, find the temperature difference in $^{o}F.$ between freezing water and the temperature you have. Then convert the temperature difference to $^{o}C.$ Add the temperature of freezing water in $^{o}C.$ (That's easy. It's $0\ ^{o}C.$) Now, you have the description of the temperature in $^{o}C.$

Here's an example:

$T = 59\ ^{o}F.$

$\Delta T = (59\ ^{o}F. - 32\ ^{o}F.) = 27\ ^{o}F.$

$\Delta T = (^{o}C./1.8\ \cancel{^{o}F.})\ 27\ \cancel{^{o}F.}$

$\Delta T = \frac{27\ ^{o}C.}{1.8}$

$\Delta T = 15\ ^{o}C.$

$T = 15\ ^{o}C. + 0\ ^{o}C. = 15\ ^{o}C.$

To go from $^{o}C.$ to $^{o}F.$, you do the same thing using the freezing water temperature in $^{o}C.$, and reverse the conversion factor:

$T - 15\ ^{o}C.$

$\Delta T = (15\ ^{o}C. - 0\ ^{o}C.) = 15\ ^{o}C.$

$\Delta T = (1.8\ ^{o}F./\cancel{^{o}C.})\ 15\ \cancel{^{o}C.}$

$\Delta T = (1.8\ ^{o}F.)\ 15$

$\Delta T = 27\ ^{o}F$

$T = 27\ ^{o}F. + 32\ ^{o}F. = 59\ ^{o}F.$

The only differences are in how you use the conversion factor, and in what the temperature of freezing water is called on the two scales.

Try the practice problems below, and check your answers in frame 29.

A. $T = 75\ ^{o}C.$

B. $T = 86\ ^{o}F.$

C. $T = 13\ ^{o}C.$

D. $T = 41\ ^{o}F.$

---

27. Remember to <u>reverse</u> the conversion factor, and make it into ($^{o}C./1.8\ ^{o}F.$). Then multiply by it and <u>cancel</u> the two $^{o}F.$ symbols. Now, since the 1.8 is in the denominator of the fraction, you <u>divide</u> by it. Here's another example:

$\Delta T = 36\ ^{o}F.$

$\Delta T = (^{o}C./1.8\ ^{o}F.)\ 36\ ^{o}F.$

$\Delta T = \dfrac{36\ ^{o}C.}{1.8}$

$\Delta T = 20\ ^{o}C.$

Try these and check your answers in frame 28.

A. $\Delta T = 90\ ^{o}F.$

B. $\Delta T = 18\ ^{o}F.$

C. $\Delta T = 108\ ^oF.$

---

28. You should have

A. $\Delta T = 50\ ^oC.$

B. $\Delta T = 10\ ^oC.$

C. $\Delta T = 60\ ^oC.$

If you didn't get those answers, go back to frame 24, and review the method. If you did, go back to frame 26.

---

29. You should have gotten

A. $T = 167\ ^oF.$

B. $T = 30\ ^oC.$

C. $T = 55.4\ ^oF.$

D. $T = 5\ ^oC.$

If you did, go to frame 32. If not, go to frame 30.

---

30. O.K. The method is a little long. But, it's simple. Here's another example of converting T from °F. to °C.

$T = 68\ ^oF.$

(32 °F. is the temperature of freezing water)

Find $\Delta T = 68\ ^oF. - 32\ ^oF. = 36\ ^oF.$

$\Delta T = (^oC./1.8\ \cancel{^oF}) \; 36\ \cancel{^oF}$

(You reverse the conversion factor to get ΔT from °F. to °C.)

$\Delta T = \dfrac{36\ ^oC.}{1.8}$

(The 1.8 is in the denominator of the conversion factor "fraction", so you divide by it.)

$\Delta T = 20\ ^oC.$

$T = 20\ ^oC + 0\ ^oC. = 20\ ^oC.$

(Add the temperature of freezing water in °C., which is 0 °C.)

Going in the reverse direction, you do the same steps, but write the conversion factor so the ^{o}C. symbols cancel: 1.8 ^{o}F./^{o}C.

Here's an example of that:

T = 40 ^{o}C.

ΔT = 40 ^{o}C. - 0 ^{o}C. = 40 ^{o}C. (0 ^{o}C. is the temperature of freezing water in ^{o}C.)

ΔT = (1.8 ^{o}F./ $\cancel{^{o}C}$.) 40 $\cancel{^{o}C}$. (Write the conversion factor so the ^{o}C. symbols cancel.)

ΔT = (1.8 ^{o}F.) 40

ΔT = 72 ^{o}F.

T = 72 ^{o}F. + 32 ^{o}F. = 104 ^{o}F. (The temperature of freezing water in ^{o}F. is 32 ^{o}F.)

O.K. Try these and check your answers in frame 31.

A. T = 30 ^{o}C.

B. T = 149 ^{o}C.

C. T = 65 ^{o}C.

D. T = 77 ^{o}F.

31. You should have

A. $T = 86\ ^oF.$

B. $T = 65\ ^oF.$

C. $T = 149\ ^oF.$

D. $T = 25\ ^oC.$

If you got these, go to frame 32. If not, go back to frame 26, and work through the process again.

---

32. A quicker shorthand for the temperature conversion process can be written down, if you use the symbol T_F for temperature in $^oF.$, and T_C for temperature in $^oC.$ You get

$$T_C = (^oC./1.8\ ^oF.)\ (T_F - 32\ ^oF.)$$

and $$T_F = (1.8\ ^oF./^oC.)\ T_C + 32\ ^oF.$$

The $(T_F - 32\ ^oF.)$ in the shorthand for conversion from T_F to T_C means "subtract the temperature of freezing water from the temperature in $^oF.$" In other words, $(T_F - 32\ ^oF.)$ is just ΔT in $^oF.$ Since the $^oC.$ temperature of freezing water is zero, you don't have to add anything to get T_C after you multiply ΔT by $(^oC./1.8\ ^oF.$

Also, since the temperature of freezing water is $0\ ^oC.$, T_C and ΔT in $^oC.$ are the <u>same</u>. So, the shorthand for conversion from T_C to T_F says you just take T_C, multiply it by the conversion factor $(1.8\ ^oF./^oC.)$ and add the temperature of freezing water in $^oF.$

So, the two formulas are complete shorthands for the conversion process you learned in frames 16 through 29.

Now, try using the two complete shorthands to convert T_C to T_F and T_F to T_C.

A. $T_F = 122\ ^oF.$

B. $T_C = 85\ ^oC.$

20

C. $T_F = 113\ ^oF.$

D. $T_C = 115\ ^oC.$

Check your answers in frame 33.

---

33. You should have

A. $T_C = 50\ ^oC.$

B. $T_F = 185\ ^oF.$

C. $T_C = 45\ ^oC.$

D. $T_F = 239\ ^oF.$

If you didn't get these answers, go to frame 34. If you did, go to frame 35.

---

34. O.K. Let's try it again. It's just a shorthand for what you've been doing already.

$T_F = (1.8\ ^oF./^oC)\ T_C + 32\ ^oF.$

just means; mult*ply the conversion factor by ΔT in ^oC. (That's the <u>same</u> as T_C because the temperature of freezing water is 0 ^oC.) Then add 32 ^oF. - the temperature of freezing water in ^oF.

$T_C = (^oC./1.8\ ^oF.)\ (T_F - 32\ ^oF.)$

just means: ΔT in ^oF. is T_F less 32 ^oF. - the temperature of freezing water in ^oF. Multiply ΔT by ($^oC./1.8\ ^oF.$). You don't have to add anything for the temperature of freezing water in ^oC. because it's zero.

Try these:

A. $T_C = 5\ ^oC.$

B. $T_F = 77\ ^oF.$

C. $T_C = 55\ ^oC$.

D. $T_F = 50\ ^oF$.

Check your answers in frame 35.

---

35. You should have:

A. $T_F = 41\ ^oF$.
B. $T_C = 25\ ^oC$.
C. $T_F = 131\ ^oF$.
D. $T_C = 10\ ^oC$.

If you got them all, go on to the review questions. If not, go back to frame 32 and review the process.

Review Questions: (Write out your answers!)

1. What is heat?

2. What is the relationship between heat and temperature?

3. How can heat be transferred from one substance to another?

4. Convert the following temperatures from ^oF. to ^oC:

   A. 86 ^oF.

   B. 113 ^oF.

   C. 32 ^oF.

5. Convert the following temperatures from ^oC. to ^oF.

   A. 40 ^oC.

B. 75 ^{o}C.

C. 105 ^{o}C.

Check your answers on the next page.

Answers to review questions:

1. Heat is the disorganized motion of the molecules and atoms of substances.
2. The faster the molecules or atoms of a substance are moving, the higher its temperature. The total amount of heat in a substance depends both on its temperature and how many atoms or molecules there are of it.
3. The faster moving molecules of the higher temperature substance hit the slower moving molecules of the lowest temperature substance and speed them up.
4. A. 30 ^{o}C.
   B. 45 ^{o}C.
   C. 0 ^{o}C.
5. A. 104 ^{o}F.
   B. 167 ^{o}F.
   C. 221 ^{o}F.

If you didn't get all the answers, review frames 1 to 35.

36. In the first section of this module you learned that heat will be <u>transferred</u> from one substance to another if there's a temperature difference (ΔT) between them. So, a substance at a higher temperature than its surroundings contains heat that can be transferred to the objects around it. The ΔT between one substance and another is due to what is called <u>sensible heat</u>.

The amount of sensible heat which is stored in a substance depends on what kind of material it is, how much of it there is, and how large a temperature difference there is between it and its surroundings. Atoms and molecules are freer to bounce around in liquids and gases than they are in solids. Atoms that can bounce around freely tend to bounce around slowly, and it takes a lot of heat energy to speed them up. That's why it usually takes more heat energy to raise the temperature of a liquid or gas than it does to raise the temperature of a solid. To raise the temperature of a liquid and a solid the same amount, you must put more sensible heat energy <u>per atom or molecule</u> into the liquid than the solid. So, the liquid will store more sensible heat than the solid for the same number of atoms and the same ΔT between the two substances and their surroundings.

Of course, the more atoms of a substance there are, the more heat energy can be stored in it. The number of atoms corresponds roughly to the weight of the substance.

List the three things that determine the amount of sensible heat stored in a substance. Check your answers in frame 37.

A.

B.

C.

---

37. You should have written:

A. Temperature difference between the substance and its surroundings (ΔT),

B. Kind of substance (solid, liquid, gas),

C. Number of atoms (weight),

or something similar. If you did, go on to frame 38. If not, return to frame 36 and go over the information again.

---

38. Good. Now you know the three things, or factors, that determine how much sensible heat is stored in a substance. The relationship between them can be written down in an equation:

$Q = WC_pT$

The symbol Q in the formula stands for the number corresponding to the total amount of sensible heat stored in the substance.

W is the symbol for the weight of the substance that's available to store sensible heat. It's just the number of pounds or kilograms of the substance that you have.

C_p is the symbol for a number called the <u>specific heat per unit weight</u> of the substance. It takes into account the number of atoms or molecules in a standard weight of the substance, such as a pound or kilogram, and how much heat energy it takes to speed up that number of atoms or molecules by an amount corresponding to a certain temperature change, such as 1 ^{o}F. or 1 ^{o}C. The specific heats of various substances can be found in tables in engineering, refrigeration, and heating manuals.

ΔT is, of course, the symbol for the temperature difference between the substance and its surroundings. It corresponds to how much faster its atoms or molecules are moving than the atoms or molecules in the surroundings.

The formula is shorthand for "To find the amount of sensible heat stored in a substance, multiply the specific heat per unit weight of the substance (say a pound or a kilogram) by the weight of the substance in pounds or kilograms and the temperature difference between the substance and its surroundings".

In the space below, write down the formula for the sensible heat stored in a substance, and give a brief definition of each of the symbols in the formula. Check your answers in frame 39.

39. You should have written

$$Q = WC_p\Delta T$$

and said something like: Q is the total amount of sensible heat stored in the substance. W is the weight of the substance, and ΔT is the temperature difference between the substance and its surroundings.

If you got all that, go on to frame 40. If not, reread frame 38 until you understand the formula, or get help from your instructor.

---

40. Sensible heat is usually described as a certain number of Calories or British Thermal Units. A Calorie is the amount of heat/energy needed to raise the temperature of a Kilogram or water by 1 $^{\circ}$C. A British Thermal Unit (abbreviated BTU) is the amount of heat/energy needed to raise the temperature of a <u>pound</u> of water by <u>1 $^{\circ}$F</u>. A Calorie is equal to 3.969 BTU, because there are 2.205 pounds of water in a Kilogram of water, and there are 1.8 $^{\circ}$F. in 1 $^{\circ}$C. 2.205 times 1.8 is equal to 3.969.

The specific heat per unit weight of water is 1 BTU per pound per $^{\circ}$F. or 1 Calorie per Kilogram per $^{\circ}$C. It works out that way because of the units we've picked to measure heat energy, BTU and Calories, and the <u>definition</u> of specific heat per unit weight. If you remember, the definition of specific heat per unit weight is the amount of heat energy needed to raise the temperature of a pound of a substance by 1 $^{\circ}$F or a Kilogram of a substance 1 $^{\circ}$C. So, because of the way we've picked to describe sensible heat energy, the specific heat per unit weight of water automatically comes out 1 BTU per pound per $^{\circ}$F. or 1 Calorie per Kilogram per $^{\circ}$C.

The specific heats per unit weight of all other substances are figured out by comparing the amount of heat it takes to raise their temperatures to the amount of heat it takes to raise the temperature of the same weight of water by the same number of $^{\circ}$F. or $^{\circ}$C. For example, suppose the same amount of heat will raise the temperature of a pound of water by 10 $^{\circ}$F., and a pound of rock by 50 $^{\circ}$F. Then, we know that it only takes one fifth as much heat to raise the temperature of the rock by 10 $^{\circ}$F. That means the specific heat of the rock is one-fifth the specific heat of water. So, the specific heat of rock is 0.2 (1/5) BTU per pound per $^{\circ}$F., or 0.2 Calories per Kilogram per $^{\circ}$C.

The abbreviation for the units of specific heat per unit weight is either (BTU/lb.-^{o}F.) or (Cal./Kg.-^{o}C.). So, you can abbreviate the specific heat per unit weight of water as 1 BTU/Lb.-^{o}F. or 1 Cal./Kg.-^{o}C. The specific per unit weight of the rock in the example would be abbreviated as 0.2 BTU/Lb.-^{o}F. or 0.2 Cal./Kg.-^{o}C.

Suppose it takes 10 times as much heat to raise the temperature of a pound of water by 10 ^{o}F. as it does to raise the temperature of a pound of steel by the same amount.

Write both abbreviations for the specific heat per unit weight of steel. Check your answers in frame 41.

---

41. You should have gotten 0.1 BTU/lb.-^{o}F. and 0.1 Cal./Kg.-^{o}C. If you did, go on to frame 44. If not, go to frame 42.

---

42. O.K. If it takes 10 times as much heat to raise the temperature of a pound of water 10 ^{o}F. as it does to do the same to a pound of steel, it takes 1/10 as much heat to raise the temperature of the steel as it does to raise the temperature of the water. The specific heat per unit weight of the steel is then one-tenth that of water. So, the specific heat per unit weight of steel is 0.1 BTU/lb.-^{o}F. or 0.1 Cal./Kg.-^{o}F.

Try this one: Suppose it takes 4 times as much heat to heat a pound of water 20 ^{o}C. as it does to do the same thing to a pound of dry air. Write down the two abbreviations for the specific heat per unit weight of dry air.

Check your answers in frame 43.

---

43. You should have .25 BTU/Lb.-^{o}F. and 0125 Cal./Kg.-^{o}C. If you don't, go back to frame 42 and review. Get help from your instructor if you need it. If you got the right answers this time, go on to frame 44.

---

44. To compute the amount of sensible heat stored in any substance, all you need to know is the weight of the substance, its specific heat per unit weight and the temperature difference between the substance and its surroundings. Then you just plug the numbers into the formula you learned in frame 38.

Let us remind you of the formula:

$Q = WC_p\Delta T$

Let's say you have 120 pounds of water, and it's 80 ^{o}F. hotter than its surroundings. You just write:

Q = (120 lb.) (1 BTU/Lb.-^{o}F.) (80 ^{o}F.)

Q = (120 (1BTU) (80)

Q = 9600 BTU

Notice how the Lb. and ^{o}F. symbols cancel out, just like when you were converting ^{o}F. into ^{o}C. Everything under the slash in BTU/Lb.-^{o}F. is treated like it's in the denominator of a fraction.

You can cancel the Lb. in 120 Lb. with the Lb. in 1 BTU/Lb.-^{o}F., and you can cancel the ^{o}F. in 80 ^{o}F. with the ^{o}F. in 1 BTU/Lb.-^{o}F. You're left with BTU, and that's how it should come out if you're trying to find an amount of sensible heat. Sensible heat is described in BTU.

Try this one:

You have 100 Lb. of rock (C_p = 0.2 BTU/Lb.-^{o}F.) at a temperature 90 ^{o}F. above its surroundings. How much sensible heat is stored in the rock?

Check your answer in frame 45.

---

45. You should have written:

$Q = WC_p\Delta T$

Q = (100 Lb.) (0.2 BTU/Lb.-^{o}F.) (90 ^{o}F.)

Q = (100) (0.2 BTU) (90)

Q = 180 BTU

If you did, go on to frame 48. If not, go to frame 46.

---

46. Just remember to plug the numbers into the formula, cancel the units, and multiply. Try this one:

60 Lb. of wood (C_p = 0.35 BTU/Lb.-^{o}F.) 20 ^{o}F. above its surroundings. Check your answer in frame 47.

---

47. You should have:

$Q = WC_p\Delta T$

$Q = (60\ \cancel{\text{Lb.}})\ (0.35\ \text{BTU}/\cancel{\text{Lb.}}\text{-}\cancel{^{o}\text{F.}})\ (20\ \cancel{^{o}\text{F.}})$

$Q = (60)\ (0.35\ \text{BTU})\ (20)$

$Q = 420$ BTU

If you got this one, go on to frame 48. If not, go back to frame 46 and review. Get help from your instructor if you need it.

---

48. Often, you'll know how big a <u>volume</u> of material you have and want to compute the amount of heat stored in it. You'll need to get the weight. You can use the density of the material and its volume to find the weight. The densities of various materials can be found in tables in engineering handbooks.

The formula for the weight is:

$W = \rho V$

V is the symbol for volume

ρ is the symbol for density. It's the Greek letter Rho, pronounced "Row." The units of density are Lb./Ft.^{3} or Lb./Gal. Ft.^{3} stands for cubic feet, and Gal. stands for gallons.

An example is that 60 gallons of water weigh about 500 Lbs. because the density of water is 8.34 Lb./Gal.:

$W = \rho V$

$W = (8.34\ \text{Lb.}/\cancel{\text{Gal.}})\ (60\ \cancel{\text{Gal.}})$

$W = (8.34\ \text{Lb.})\ (60)$

$W = 500$ Lb.

Notice that the two Gal. units cancel.

You can combine the formula for sensible heat with the formula for W to get

$Q = \rho V C_p \Delta T$

ρV is just substituted for the W in $Q = WC_p\Delta T$.

Try this problem:

You have 300 cubic feet ($Ft.^3$) of fist-sized rocks in a rock heat storage bin. Taking into account the spaces between the rocks, the density is 60 $Lb./Ft.^3$. The specific heat of rock is 0.2 BTU/Lb.-^oF. The bin's temperature is 50 ^oF. above the air temperature around it. How much heat is stored in the rock bin? Check your answer in frame 49.

---

49. You should have used:

$Q = \rho V C_p \Delta T$

$Q = (60\ Lb./Ft.^3)\ (300\ Ft.^3)\ (0.2\ BTU/Lb.\text{-}^oF.)\ (50\ ^oF.)$

$Q = (60)\ (300)\ (0.2\ BTU)\ (50)$

$Q = 180{,}000\ BTU$

If you got it, go on to frame 52. If not, go to frame 50.

---

50. In the formula

$Q = \rho V C_p \Delta T$

ρV is the weight of the substance, because $\rho V = W$. Using the new formula is the same as using the old one, except that you can find the stored heat without knowing the weight. All you need to do is look up the density and specific heat of the substance in a table.

Try this one:

100 cubic feet ($Ft.^3$) of water

Density of water is 62.4 $Lb./Ft.^3$

Water temperature 50 ^oF. above its surroundings.

Check your answer in frame 51.

51. You should have:

$$Q = \rho V C_p \Delta T$$

$$Q = (62.4\ \cancel{Lb.}/\cancel{Ft.}^3)\ (100\ \cancel{Ft.}^3)\ (1\ BTU/\cancel{Lb.}\text{-}\cancel{^oF.})\ (50\ \cancel{^oF.})$$

$$Q = 312{,}000\ BTU$$

If you got this one, go on to frame 52. If not, go back to frame 44 and review. Get help if you have trouble.

52. Most of the time you'll know how much heat you want to store. You'll also have a pretty good idea how hot your storage tank or storage bin can get without causing you too much trouble. What you won't know is the volume you need.

To get the volume, you can reverse the last formula you learned:

$$Q = \rho V C_p \Delta T$$

and make it into

$$V = \frac{Q}{\rho V C_p \Delta T}$$

You can divide by everything below the horizontal line. To make the units come out right, you use the reversing trick you used in converting $^oF.$ into $^oC.$ You reverse the units on all the numbers below the line, and then multiply. Here's an example:

You want to store 1,000,000 BTU in water at a temperature 50 ^{o} above its surroundings:

The density of water is 62.4 Lb./Ft.^{3}

$$V = \frac{Q}{\rho C_p \Delta T}$$

$$V = \frac{1{,}000{,}000\ BTU}{(62.4\ Lb./Ft.^3)\ (1\ BTU/Lb.\text{-}\cancel{^oF.})\ (50\ \cancel{^oF.})}$$

$$V = \frac{1{,}000{,}000\ \cancel{BTU}\ (Ft.^3/\cancel{Lb.})\ (\cancel{Lb.}/\cancel{BTU})}{(62.4)\ (1)\ (50)}$$

$$V = \frac{1{,}000{,}000 \text{ Ft.}^3}{(62.4)\ (1)\ (50)}$$

$$V = \frac{1{,}000{,}000 \text{ Ft.}^3}{3120}$$

$$V = 320.5 \text{ Ft.}^3$$

Try this problem:

You want to store 2,500,000 BTU in a rock bin at a temperature of 140 ^{o}F. You want to use it to heat a 70 ^{o}F. house. The rocks weigh 60 Lb./Ft.^{3} and their specific heat is 0.2 BTU/Lb.-^{o}F.

Check your answer in frame 53.

---

53. First you need to find ΔT, the difference in temperature between the rock bin and the house. (The house is the <u>surroundings</u>.) Of course, ΔT is 70 ^{o}F. Now you can use the formula:

$$V = \frac{Q}{\rho C_p \Delta T}$$

$$V = \frac{2{,}500{,}000 \text{ BTU}}{(60\ \cancel{\text{Lb.}}/\text{Ft.}^3)\ (0.2\ \text{BTU}/\cancel{\text{Lb.}}\text{-}\cancel{^{o}\text{F.}})\ (70\ \cancel{^{o}\text{F.}})}$$

$$V = \frac{2{,}500{,}000\ \cancel{\text{BTU}}\ (\text{Ft.}^3/\cancel{\text{Lb.}})\ (\cancel{\text{Lb.}}/\cancel{\text{BTU}})}{(60)\ (0.2)\ (70)}$$

$$V = \frac{2{,}500{,}000 \text{ Ft.}^3}{840}$$

$$V = 2976.2 \text{ Ft.}^3$$

If you got it, good job! Go on to frame 56. If you didn't, don't be discouraged. It was pretty hard. Go to frame 54 for a bit more practice.

---

54. You probably can do this next one without any help. Just remember the formula for V and remember how to cancel the units out by reversing the ones below the line and multiplying by them.

How much volume do you need to store 2,500,000 BTU in water at 120 ^{o}F.? You want to use the heat in the water to heat a house to 70 ^{o}F. The density of water is 62.4 Lb./Ft.^{3}. Check your answer in frame 55.

---

55. You should have $\Delta T = 50\ ^{o}F.$ and

$$V = \frac{Q}{\rho C_p \Delta T}$$

$$V = \frac{2,500,000 \text{ BTU}}{(62.4 \text{ Lb./Ft.}^3)(1 \text{ BTU/Lb.-}^oF.)(50\ ^oF.)}$$

$$V = \frac{2,500,000 \cancel{\text{BTU}} (\text{Ft.}^3/\cancel{\text{Lb.}})(\text{Lb./}\cancel{\text{BTU}})}{(62.4)(1)(50)}$$

$$V = \frac{2,500,000 \text{ Ft.}^3}{3120}$$

$$V = 801.3 \text{ Ft.}^3$$

If you got it, you're doing fine. Go on to frame 56. If not, you probably will be after you review frames 52, 53, 54, and this one. Get some help if you have trouble.

---

56. Rock storage bins and water tanks are the two main ways to store sensible heat. You should be able to compute the volume you need by now. How you get the heat into and out of the storage tank or bin is one of the subjects discussed in the next module.

As you've probably guessed, a bin or tank which can store enough heat to heat a house for several days has to be pretty large. That's because it's too expensive to insulate the container well enough to prevent heat from leaking if it gets too hot (much above 140 ^{o}F.) and you need millions of BTU to keep an average house warm for more than a couple of cold winter days.

Rocks and water are used most often to store heat because they're inexpensive. They weigh a lot, though, so the containers that hold them have to be pretty strong. That costs money.

The main disadvantages of these methods are the size and cost of the containers. Go on to the review questions.

Review Questions: (Write out your answers!)

1. What is sensible heat?

2. What are the three things that determine the amount of sensible heat stored in a substance?

3. List two commonly used ways to store sensible heat.

4. Write the formula for the amount of sensible heat stored in a certain weight of a substance.

5. Write the formula for the amount of sensible heat stored in a certain volume of a substance.

6. Explain the meanings of symbols used in the formulas for sensible heat.

7. Write the formula for the volume required to store a known amount of sensible heat.

8. How much volume would be required to store 250,000 BTU in water whose temperature was raised 70 ^{o}F. above its surroundings? (The density of water is 8.34 Lb./Gal.)

9. How much volume would be required to store 250,000 BTU in rocks whose temperature was raised 70 ^{o}F. above their surroundings? (Specific heat of rocks: 0.2 BTU/Lb. Density: about 60 Lb./Ft.^{3} allowing for the spaces between them.)

10. What are the main disadvantages of using the rock bins or water tanks to store sensible heat?

Check your answers on the next page.

Answers to review questions:

1. Sensible heat is the heat contained in a substance whose temperature is higher than the temperature of its surroundings.
2. The type of materials, the amount, and the temperature difference between it and its surroundings.
3. Water tanks and rock storage bins.
4. $Q = WC_p\Delta T$
5. $Q = \rho VC_p\Delta T$
6. Q stands for sensible heat.
   W stands for weight.
   ρ stands for density.
   V stands for volume.
7. $V = \dfrac{Q}{\rho C_p \Delta T}$
8. About 428 gal.
9. About 300 $Ft.^3$
10. The size and cost of the containers.

If you didn't get them all, review frames 36 to 56.

57. You may have been wondering why the heat stored in a substance which is at a higher temperature than its surroundings is called sensible heat. It gets its name from the fact that it can be detected, or sensed, with a thermometer.

There's another kind of heat which can also be stored in certain types of substances. It's called <u>latent</u> heat. Latent means hidden.

Latent heat is heat energy that can't be detected with a thermometer. Latent heat is the heat required to melt a solid or vaporize (boil) a liquid. The most common processes which involve latent heat are the melting of ice and boiling of water.

The molecules in a block of ice are tied together by electric forces, just like the molecules in any other solid. When a mixture of water and ice is heated, the heat energy first goes into freeing more molecules in the ice from the electrical forces, rather than speeding up the already free molecules. Until all the ice molecules have broken free from each other, none of the water molecules will be speeded up.

As long as no water molecules are speeding up, the temperature of the water-ice mixture isn't rising. But heat energy is being put into the ice molecules in order to break them free from each other. The heat energy that it takes to melt ice is latent heat energy, because the temperature of the ice won't change until it's all melted into water.

The heat energy that went into melting the ice can be recovered by allowing it to freeze again. Only the slow-moving water molecules that hit each other will stick together to form ice. As long as there are any fast-moving ones, the water won't all freeze.

Every water molecule will have to transfer some of its heat energy to either the ice that's forming or the surroundings in order to slow down enough to stick to the others. Until that happens, there will still be some faster-moving water molecules, and the temperature of the water-ice mixture will stay the same. The temperature of a water-ice mixture stays the same until either enough heat is added to melt all the ice, or enough heat is removed to freeze all the water.

Describe the difference between sensible and latent heat, and check your answer in frame 58.

58. Sensible heat is heat stored due to a temperature difference between a substance and its surroundings. (It can be detected with a thermometer.)

Latent heat is the heat required to melt a solid or vaporize (boil) a liquid. The temperature of a solid-liquid or liquid-vapor mixture won't change until the mixture gains or loses enough heat to become all solid, all liquid, or all vapor. The heat that's added or removed is called latent heat because it's hidden, and can't be detected with a thermometer.

If your answer resembled the one above, go on to frame 59. If not, return to frame 57 and review.

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59. When a liquid freezes or boils, or a solid melts, the change is called a phase change. All phase changes require the addition or removal of latent heat.

It's usually inconvenient to store latent heat by melting a solid, and recover it by allowing the solid to freeze. That's because there are no pure solids that freeze at temperatures which are convenient for storing the heat. Heat stored at low temperatures can't be easily transferred to substances at higher temperatures. You can't easily use the heat in a water-ice mixture to heat your living room.

Heat stored at high temperatures tends to leak away too quickly. Storing heat in gases, like steam, also takes too much volume, because the molecules in gases are so far apart.

However, there are processes similar to phase changes which also involve latent heat, and which occur at convenient temperatures. They can be used to store heat which can later be recovered to do such things as heat buildings.

One such process is the dissolving of a solid like salt into a liquid like water. That process requires latent heat and can be made to occur at almost any desired temperature. When the solid crystallizes back out of the liquid, the latent heat is released.

Another such process is the attachment and removal of excess water molecules, called water of hydration, from certain salts. The salts are called salt hydrates. Common examples are sodium sulfate ($Na_2\,SO_4 \cdot 10\,H_2O$), sodium thiosulfate ($Na_2\,S_2O_3 \cdot 5\,H_2O$) and disodium phosphate ($Na_2\,HPO_4 \cdot 12\,H_2O$). Removal of the water molecules requires heat, and their reattachment releases it.

Name two processes similar to the phase changes between solids and liquids and gases which can be used to store latent heat. Check your answers in frame 60.

---

60. The two processes are the dissolving of salts in liquids, and the attachment and removal of water of hydration from certain salts. These processes can be made to occur at temperatures enough above room temperature so the heat from them can be easily transferred into a room when necessary. Typical temperatures are between 90 ^{o}F. and 140 ^{o}F.

The amount of latent heat stored in a substance depends on how much of it there is, and what kind of a process is involved. The amount of the substance is best described by its weight. The process is described by a number called the latent heat per unit weight. The symbol for latent heat per unit is L.

Write the symbols for the two important quantities that determine the amount of latent heat contained in a substance, and explain what they stand for. Check your answers in frame 61.

---

61. The symbols are

W, which stands for the weight, or amount of the substance.

L, which stands for the <u>latent heat per unit weight</u> of the substance. It can be looked up in tables in chemistry handbooks.

We hope you remembered that W is the symbol for weight. Go on to frame 62.

---

62. The formula you use to compute the latent heat contained in a substance is

$Q = WL$

Q still stands for heat, and it's usually described in BTU. W is usually described in pounds, and L is usually described in BTU/Lb. You cancel the two Lb. symbols just like you do in the formula for sensible heat.

100 Lb. of sodium sulfate ($Na_2\ SO_4 \cdot 10\ H_2O$) with a latent heat of hydration of 108 BTU/Lb. contain 10,800 BTU of latent heat energy:

$Q = WL$

$Q = (100\ \text{Lb.})\ (108\ \text{BTU/Lb.})$

$Q = 10{,}800\ \text{BTU}$

Try this one:

How much latent heat energy is contained in 200 Lb. of sodium thiosulfate ($a_2\ S_2O_3 \cdot 5\ H_2O$) with a latent heat of hydration of 120 BTU/Lb.?

Check your answer in frame 63.

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63. You should have

$Q = 24{,}000\ \text{BTU}$

If you didn't get it, review frame 62 and try again. When you get it, go on to frame 64.

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64. Using a dissolved salt or water of hydration and a hydrated salt is the most efficient way to store heat. A large amount of latent heat can be stored in a small amount of such a material. A convenient constant temperature can be chosen because the material can store heat without a rise in temperature.

Write in your own words the two advantages of using dissolved or hydrated salts for heat storage. Check your answers in frame 65.

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65. You should have written something like:

A large amount of heat can be stored in a small amount of material, and the heat can be stored at a convenient constant temperature.

Easy, wasn't it? It wasn't? Go back and reread frame 64. Otherwise, onward to frame 66!

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66. Good. You've got the idea. Go on to frame 67.

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67. The main difficulty with both techniques is that once the water and salt have separated, releasing the stored heat, it can be difficult for them to recombine when they are reheated. The salt tends to concentrate in a small volume of the storage container. When that happens, the water is only in contact with a small amount of salt on the surface of the salt volume, and can't recombine with the rest.

The only way to avoid the difficulty is to spread the salt out so most of it is in contact with the water, even when the water and salt aren't bound together. This can be done by laying the salt in trays under a shallow layer of water. Of course, the trays must be separated from each other in racks, so the storage container gets more complex, expensive, and larger.

There are other subtle chemical problems that have plagued this technique, but the experts seem to have solved them. Salt heat storage systems have been put through thousands of cycles of heat storage and release without losing their ability to store heat. However, they are best left to experts.

Describe the major drawback of salt heat storage systems in your own words. Check your answer in frame 68.

68. If you wrote that it's difficult to keep all of the salt in contact with the water when they split apart, you understand. Good. Go on to frame 69. If you didn't, review frame 67.

69. Congratulations. You've finished the programmed material. Good luck on the review and post-test.

Review Questions: (Write out your answers!)

1. What's the difference between sensible heat and latent heat?

2. What are the two main methods used to store latent heat?

3. What are the two main advantages of using latent heat as stored heat?

4. What's the major disadvantage of using latent heat storage?

5. Compute the amount of latent heat stored in 400 Lbs. of sodium thiosulfate ($Na_2 S_2O_3 \cdot 5 H_2O$)

   $L = 90$ BTU/Lb.

Check your answers on the next page.

Answers to Review Questions:

1. Sensible heat is the heat stored in a substance due to a difference in temperature between the substance and its surroundings. It can be detected, or sensed with a thermometer. Latent heat is the heat required to make a substance change from one physical state to another. For example: The heat required to dissolve salts in water, or remove water of hydration from hydrated salts. Processes involving latent heat don't involve changes in the temperature of the substances involved, so the (stored) heat can't be detected with a thermometer.
2. Dissolved salts and hydrated salts.
3. A large amount of heat can be stored in a small space. Latent heat can be stored at almost any convenient temperature.
4. The difficulty of keeping the salt in physical contact with the water when they're not bound together chemically.
5. 36,000 BTU.

If you missed any, go back and review frames 57 through 69.

Post-Test:

1. What's the difference between heat and temperature?

2. Convert the following temperatures from $^{o}C.$ to $^{o}F.$

   70 $^{o}C.$

   10 $^{o}C.$

   25 $^{o}C.$

3. Convert the following temperatures from $^{o}F.$ to $^{o}C.$

   40 $^{o}F.$

   78 $^{o}F.$

   98 $^{o}F.$

4. How can heat be transferred between two substances at different temperatures?

5. How much sensible heat is stored in 300 $Ft.^3$ of concrete ($Cp = 0.25$ BTU/Lb. - $^{o}F.$; $p = 150$ $Lb./Ft.^3$) at a temperature 50 $^{o}F.$ above its surroundings?

6. What are the two substances most used to store sensible heat?

7. What are the two difficulties encountered in storing sensible heat?

8. What's the difference between sensible heat and latent heat?

9. How much latent heat is stored in 250 Lb. of disodium phosphate (Na_2HPO_4)? $L = 120$ BTU/Lb.

10. What are the two main advantages of storing heat as latent heat?

11. What's the main difficulty in storing latent heat?