

Physics 4C

Chapter 18: Temperature, Heat, and the First Law of Thermodynamics

“Anyone who has never made a mistake has never tried anything new.” – Albert Einstein

“Experience is the name that everyone gives to his mistakes.” – Oscar Wilde

Reading: pages 476 – 498

Outline:

- ⇒ temperature and the zeroth law of thermodynamics
- ⇒ thermometers and temperature scales
- ⇒ thermal expansion
 - linear expansion
 - volume expansion
 - unusual behavior of water (PowerPoint)
- ⇒ temperature and heat
 - definition of heat
 - specific heat
 - heat of transformation
 - heat and work
- ⇒ first law of thermodynamics
 - definition
 - special cases
- ⇒ heat transfer mechanisms
 - conduction
 - convection
 - radiation

Problem Solving Techniques

Some problems of this chapter deal with the definition of temperature. You will need to manipulate the relationship $T_1/T_2 = x_1/x_2$, where x_1 is the value at temperature T_1 of some property of a object that is used to measure temperature (the pressure of a gas, for example) and x_2 is the value of the same property at temperature T_2 . You must know three of the quantities that appear in the equation or else the ratio of two of them and the value of a third, then you can solve for the fourth. In some cases, one of the temperatures is the triple point of water, 273.16 K. In some cases, the pressure of a gas is used and you must take the limit as the amount of gas becomes vanishingly small.

You should know how to convert from one common temperature scale to another. The relevant equations are $T_C = T - 273.15$ (Kelvin to Celsius) and $T_F = (9/5)T_C + 32^\circ$ (Celsius to

Fahrenheit). The most straightforward problems give the temperature on one scale and ask for the temperature on another.

Another set of problems is concerned with thermal expansion. The important relationship is $\Delta L = \alpha L \Delta T$. You might be given the original length L , the coefficient of linear expansion α , and the temperature change ΔT , then asked for the change in length ΔL or else the new length $L + \Delta L$. In other problems, you might be asked for the temperature change required to achieve a given change in length or a given final length. Sometimes the lengths for two different temperatures are given and you must calculate the coefficient, assumed to be independent of temperature. The fractional change $\Delta L/L$ might be given instead of the initial and final lengths. In some cases, you are asked to compare the expansions of two objects.

Some thermal expansion problems deal with areas and volumes. These are essentially the same as the problems dealing with linear dimensions but the coefficient of expansion is different. If α is the coefficient of linear expansion, then 2α is the coefficient of area expansion and 3α is the coefficient of volume expansion. Some problems deal with two objects in contact. Each individually obeys the law of thermal expansion and the sum of the two expansions is the total expansion of the composite system.

The heat of transformation is the energy per unit mass transferred as heat during a phase change. It is a property of the material that is changing phase. In the equation $Q = mL$, m is the mass of material that undergoes a phase change and is not necessarily the mass of all the material present.

If there is no phase change, the energy Q absorbed or released as heat by a substance is related to the change in temperature ΔT by $Q = C\Delta T$, where C is the heat capacity, or by $Q = mc\Delta T$, where m is the mass and c is the specific heat.

You should know how to calculate the final temperature of two or more objects, initially at different temperatures, when they have been in contact long enough to achieve thermal equilibrium. Use the condition that the energy rejected as heat by one object is absorbed as heat by the others. If the final temperature is known, this condition can be used to calculate the specific heat or mass of one of the objects.

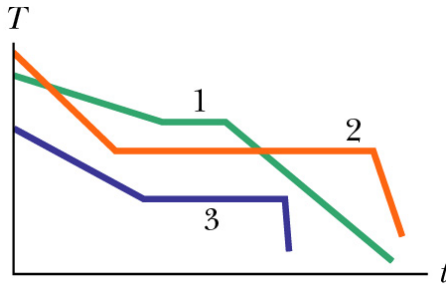
Some problems test your understanding of the first law of thermodynamics: $\Delta E_{\text{int}} = Q - W$. Be sure you understand the sign convention you must use with this equation.

Thermal conductivity problems all involve $P_{\text{cond}} = kA(T_H - T_C)/L$. Usually all but one of the quantities that appear in this equation are given and you are asked for the other one. More complicated problems involve several rods, for example, welded either end to end or side by side. In the first case, the rate of energy conduction must be the same in all rods, while in the second it is the sum of the rates for the individual rods. In other problems, the energy transfer accomplishes a purpose, such as the melting of ice at one end of a rod.

Questions and Example Problems from Chapter 18

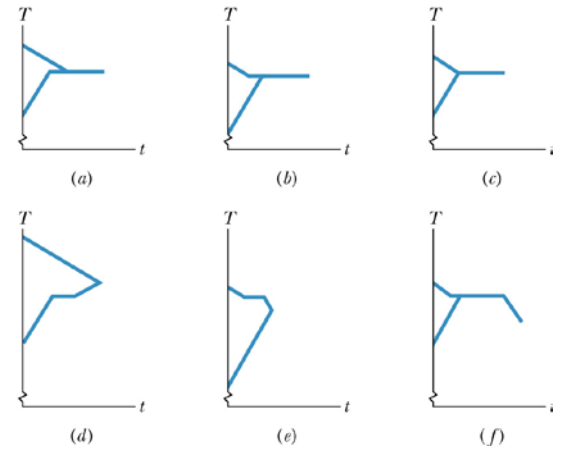
Question 1

Three different materials of identical masses are placed, in turn, in a special freezer that can extract energy from a material at a certain constant rate. During the cooling process, each material begins in the liquid state and ends in the solid state; the figure below shows graphs of the temperature T versus time t for the three materials. (a) For material 1, is the specific heat for the liquid state greater than or less than that for the solid state? Rank the materials according to (b) their freezing-point temperatures, (c) their specific heats in the liquid state, (d) their specific heats in the solid state, and (e) their heats of fusion, all greatest first.



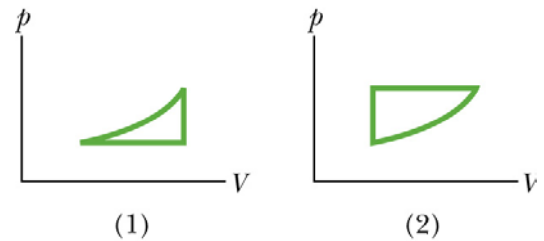
Question 2

A sample A of liquid water and a sample B of ice, of identical masses, are placed in a thermally isolated (insulated) container and allowed to come to thermal equilibrium. Graphs b through f are additional sketches of T versus t , of which one or more are impossible to produce. (a) Which is impossible and why? (b) In the possible ones, is the equilibrium temperature above, below, or at the freezing point of water? (c) As the possible situations reach equilibrium, does the liquid partly freeze, fully freeze, or undergo no freezing? Does the ice partly melt, fully melt, or undergo no melting?



Question 3

The figure shows two closed cycles on p - V diagrams for a gas. The three parts of cycle 1 are of the same length and shape as those of cycle 2. For each cycle, should the cycle be traversed clockwise or counterclockwise if (a) the net work W done by the gas is to be positive and (b) the net energy transferred by the gas as heat Q is to be positive?



Problem 1

At what temperature is the Fahrenheit scale reading equal to (a) twice that of the Celsius and (b) half that of the Celsius?

Problem 2

An aluminum-alloy rod has a length of 10.000 cm at 20.000°C and a length of 10.015 cm at the boiling point of water. (a) What is the length of the rod at the freezing point of water? (b) What is the temperature if the length of the rod is 10.009 cm?

Problem 3

At 20°C , a rod is exactly 20.05 cm long on a steel ruler. Both the rod and the ruler are placed in an oven at 270°C , where the rod now measures 20.11 cm on the same ruler. What is the coefficient of thermal expansion for the material of which the rod is made?

Problem 4

What mass of steam at 100.0°C must be mixed with 150.0 g of ice at its melting point, in a thermally isolated container, to produce liquid water at 50.0°C ?

Problem 5

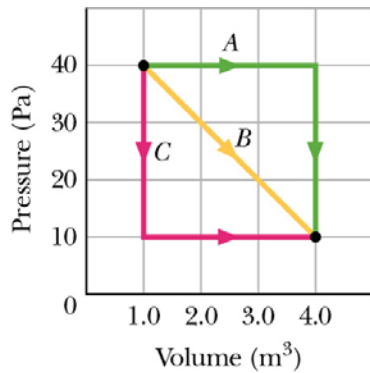
Calculate the minimum amount of energy, in joules, required to completely melt 130.0 g of silver initially at 15.0°C.

Problem 6

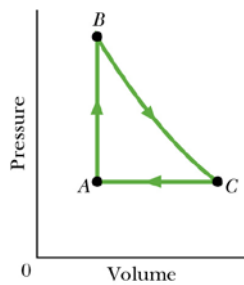
Two 50.0 g ice cubes are dropped into 200.0 g of water in a thermally insulated container. If the water is initially at 25.0°C, and the ice comes directly from a freezer at -15.0°C , what is the final temperature at thermal equilibrium?

Problem 7

A sample of gas expands from 1.0 m^3 to 4.0 m^3 while its pressure decreases from 40 Pa to 10 Pa . How much work is done by the gas if its pressure changes with volume via each of the three paths shown in the p - V diagram in the figure below?

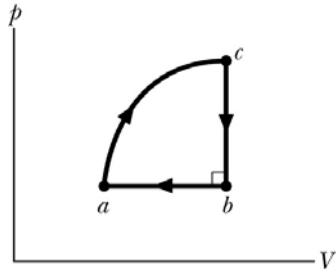
**Problem 8**

Gas within a chamber passes through the cycle shown in the figure below. Determine the energy transferred by the system as heat during process CA if the energy added as heat Q_{AB} during process AB is 20.0 J , no energy is transferred as heat during process BC, and the net work done during the cycle is 15.0 J .



Problem 9

The figure below shows a closed cycle for a gas. From c to b , 40 J is transferred from the gas as heat. From b to a , 130 J is transferred from the gas as heat, and the magnitude of the work done by the gas is 80 J. From a to c , 400 J is transferred to the gas as heat. What is the work done by the gas from a to c ? (*Hint*: You need to supply the plus and minus signs for the given data.)

**Problem 10**

A cylindrical copper rod of length 1.2 m and cross-sectional area 4.8 cm^2 is insulated to prevent heat loss through its surface. The ends are maintained at a temperature difference of 100 C° by having one end in a water-ice mixture and the other in boiling water and steam. (a) Find the rate at which energy is conducted along the rod. (b) Find the rate at which ice melts at the cold end.

Problem 11

(a) What is the rate of energy loss in watts per square meter through a glass window 3.0 mm thick if the outside temperature is -20°F and the inside temperature is $+72^{\circ}\text{F}$? (b) A storm window having the same thickness of glass is installed parallel to the first window, with an air gap of 7.5 cm between the two windows. What now is the rate of energy loss if conduction is the only important energy-loss mechanism?

Problem 12

If you were to walk briefly in space without a spacesuit while far from the Sun (as an astronaut does in the movie 2001), you would feel the cold of space—while you radiated energy, you would absorb almost none from your environment. (a) At what rate would you lose energy? (b) How much energy would you lose in 30 s? Assume that your emissivity is 0.90, and estimate other data needed in the calculations.