Chapter 12

TEMPERATURE AND HEAT

PREVIEW

The total internal energy of the molecules of a substance is called *thermal energy*. The *temperature* of a substance is a measure of the average kinetic energy of the molecules in the substance, and gives an indication of how hot or cold the substance is relative to some standard. The energy transferred between two substances because of a temperature difference is called *heat*. Many substances expand when heated.

The content contained in sections 1, 2, 4, 6 – 8, and 11 (not including volume expansion) of chapter 12 of the textbook is included on the AP Physics B exam.

QUICK REFERENCE

Important Terms

absolute zero
: the lowest possible temperature, at which all molecular motion would cease and a gas would have no volume.

calorie
: the amount of heat required to raise the temperature of one gram of water by one Celsius degree

Celsius (C)
: temperature scale in which the freezing point of water is 0 and the boiling point of water is 100 .

heat
: the energy which is transferred from one body to another because of a temperature difference

Kelvin (absolute) temperature scale
: scale in which zero Kelvins is defined as absolute zero, the temperature at which all molecular motion ceases

temperature
: the property of a body which indicates how hot or cold a substance is with respect to a standard

thermal energy
: the sum of the internal potential and kinetic energy of the random motion of the molecules making up an object

thermal equilibrium
: state between two or more objects in which temperature doesn’t change

thermal expansion
: increase in length or volume of a material due to an increase in temperature

Equations and Symbols

$T_K = T_C + 273.15$

$\Delta L = \alpha L_o \Delta T$

where

T_K = Kelvin temperature
T_C = Celsius temperature
ΔT = change in temperature
ΔL = change in length
L_o = initial length
α = coefficient of linear expansion

Ten Homework Problems

Chapter 12 Conceptual Questions 1, 3, 5, 11, 15, Problems 9, 14, 17, 19, 21

DISCUSSION OF SELECTED SECTIONS

12.1 and 12.2 Common Temperature Scales and The Kelvin Temperature Scale

Temperature is the measure of how hot or cold a substance is relative to some standard. It is the measure of the *average kinetic energy* of the molecules in a substance. The two temperature scales used most widely in scientific applications is the Celsius scale and the Kelvin scale. The only difference between them is where each starts. On the Celsius scale, the freezing point of water is 0° C, and the boiling point of water (at standard pressure) is 100° C. The Kelvin scale has temperature units which are equal in size to the Celsius degrees, but the temperature of 0 Kelvin is *absolute zero*, defined as the temperature at which all molecular motion in a substance ceases. Zero Kelvin is equal to - 273.15° C, so we can convert between the Kelvin scale and the Celsius scale by the equation

$T_K = T_C + 273$

Note that we have rounded 273.15 to 273. The boiling point of water in Kelvins would be T_K = 100° C + 273 = 373 K.

12.4 Linear Thermal Expansion

When a solid is heated, it typically expands. Different substances expand at different rates, which is why you might heat the lid of a jar when the lid is too tight. The metal lid will expand more than the glass jar when it is heated, making it easier to loosen. Solids undergo two types of expansion when heated: linear thermal expansion, which is the increase in any one dimension of the solid, and volume thermal expansion, which results in an increase in the volume of the solid. Volume expansion is not typically covered on

the AP Physics B exam. In the case of linear expansion, the change in length ΔL is proportional to the original length L_o and the change in temperature ΔT of the solid:

$$\Delta L = \alpha L_o \Delta T$$

where α is the coefficient of linear expansion.

Example 1 The ends of a copper bar and a steel bar, each of length 0.20 m, are separated by a gap of 0.50 mm, as shown. The other ends of the bars are attached to a rigid frame which does not expand significantly when heated. If the two bars are heated from 0° C to 100° C, determine whether or not the bars will come into contact with each other.

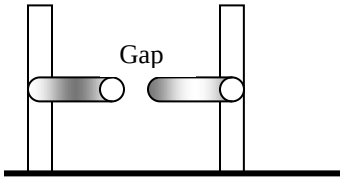

Figure not drawn to scale

Solution
Since the frame is rigidly attached to the floor, we can assume the expansion of each bar is toward the other bar. Finding the change in length of each bar:
Copper:
$$\Delta L = \alpha L_o \Delta T = \left(17\,x10^{-6}\,C^{-1}\right)\left(0.20\,m\right)\left(100°C - 0°C\right) = 3.4\,x10^{-4}\,m$$
Steel:
$$\Delta L = \alpha L_o \Delta T = \left(12\,x10^{-6}\,C^{-1}\right)\left(0.20\,m\right)\left(100°C - 0°C\right) = 2.4\,x10^{-4}\,m$$
Adding the two changes in length, we get 5.8 x 10^{-4} m = 0.58 mm. Thus the 0.50 mm gap will close and the bars will come into contact with each other.

12.6 Heat and Internal Energy

In any state of matter, the molecules are moving and therefore have energy. They have potential energy because of the bonds between them and kinetic energy because the molecules have mass and speed. The sum of the potential and kinetic energies of the molecules in a substance is called the *internal energy* of the substance. When a warmer substance is brought in contact with a cooler substance, some of the kinetic energy of the molecules in the warmer substance is transferred to the cooler substance. The energy representing the kinetic energy of molecules that is transferred spontaneously from a warmer substance to a cooler substance is called *heat energy*. Heat is generally given the symbol *Q*, and, since it is a form of energy, is measured in Joules (J) or calories (cal).

CHAPTER 12 REVIEW QUESTIONS

For each of the multiple choice questions below, choose the best answer.

1. The average kinetic energy of the molecules in a substance is most closely associated with
(A) heat
(B) temperature
(C) expansion
(D) absolute zero
(E) potential energy

2. The Celsius temperature at absolute zero is equal to
(A) 0° C
(B) 100° C
(C) 273° C
(D) – 273° C
(E) – 100° C

3. Which of the following is true of the Celsius and Kelvin temperature scales?
(A) Both the Celsius and Kelvin temperature scales have negative values.
(B) A Kelvin degree and a Celsius degree are equivalent in size.
(C) A Kelvin degree is larger in size than a Celsius degree.
(D) A Kelvin degree is smaller in size than a Celsius degree.
(E) The Kelvin scale reaches much higher temperatures than the Celsius scale.

4. In general, when a solid is heated, it
(A) expands proportionally to the change in temperature
(B) contracts proportionally to the change in temperature
(C) expands inversely proportionally to the change in temperature
(D) contracts inversely proportionally to the change in temperature
(E) does not expand nor contract.

5. A brass spring has a spring constant *k*. When the spring is heated, the spring constant will
(A) increase
(B) decrease
(C) remain the same
(D) increase, then decrease
(E) decrease then increase

6. Which of the following statement(s) is/are true?

I. Every substance contains heat.
II. For heat to flow between two substances, they must be at different temperatures.
III. The internal energy of a substance is equal to the kinetic energy of the molecules in the substance.

(A) I and II only
(B) II and III only
(C) II only
(D) III only
(E) I, II, and III

ANSWERS AND EXPLANATIONS TO CHAPTER 12 REVIEW QUESTIONS

Multiple Choice

1. B
The temperature of a substance is proportional to the average kinetic energy of its molecules.

2. D
$T_C = T_K - 273 = 0 - 273 = -273°$ C

3. B
The Kelvin and Celsius degrees are equivalent in size, they are simply offset by 273.

4. A
In the equation $\Delta L = \alpha L_o \Delta T$, the coefficient of linear expansion α and the initial length of the metal L_o are both constants. Thus the change in length is proportional to the change in temperature.

5. B
A heated spring will lengthen, causing the spring to be less stiff, and the spring constant to decrease.

6. C
Heat can only be transferred between substances of different temperatures. It is not proper to say that a substance *contains* heat, but heat is the energy transferred between two substances. The internal energy is the sum of the kinetic and potential energy of the molecules in a substance.