UCAR CENTER FOR SCIENCE EDUCATION

Answer Key for Blackbody Radiator Assessment Questions

1. When an object is in a state of thermal equilibrium, which of the following statements about energy flow is most accurate?

a) More energy **flows to** the object than away from it.
b) The flow of energy to the object is about the same as the flow of energy away from the object. (correct)
c) More energy **flows away from** the object than to it.
d) More information is needed to answer this question.

2. If an object receives more energy than it emits, what would you expect to happen to the average temperature of that object?

a) The object would become warmer. (correct)
b) The temperature of the object would stay about the same.
c) The object would become cooler.
d) More information is needed to answer this question.

3. If an object gives off more energy than it receives, what would you expect to happen to the average temperature of that object?

a) The object would become warmer.
b) The temperature of the object would stay about the same.
c) The object would become cooler. (correct)
d) More information is needed to answer this question.

4. Suppose you had two black, iron spheres. Sphere A has a temperature of 100° C (212° F). Sphere B has a temperature of 0° C (32° F). What can you say about the infrared heat energy being emitted by these two spheres?

a) Both spheres are radiating infrared heat energy. Sphere A is emitting more energy than sphere B. (correct)
b) Both spheres are radiating infrared heat energy. Sphere B is emitting more energy than sphere A.
c) Both spheres are radiating about the same amount of infrared heat energy.
d) Neither sphere is radiating infrared heat energy.
e) Only sphere A is radiating infrared heat energy.
f) Only sphere B is radiating infrared heat energy.

5. Suppose you had two black, iron spheres and an instrument that could measure the amount of electromagnetic radiation being emitted by each sphere. Your measurements show that sphere A is emitting less electromagnetic radiation than sphere B. What, if anything, can you conclude about the temperatures of the two spheres?

a) These measurements would not tell me anything about the temperatures of the spheres.
b) The spheres have the same temperature.
c) Sphere A is warmer than sphere B.
d) Sphere B is warmer than sphere A. (correct)

Calculations

1. Suppose you had two black, iron spheres. Sphere A has a temperature of 20° C. Sphere B has a temperature of 40° C. Calculate the relative amount of electromagnetic radiation being emitted by sphere B compared to sphere A.

First **convert temperature values** from degrees Celsius to kelvins:

$$T_{A,Kelvin} = T_{A,Celsius} + 273.15 = 293.15\ kelvins$$

$$T_{B,Kelvin} = T_{B,Celsius} + 273.15 = 313.15\ kelvins$$

Assuming the two spheres are the same size, calculate the energy emission rate (j^*, in units of energy per unit area per unit time) using the Stefan-Boltzmann Law:

$$j^* = \sigma T^4$$

T = temperature in kelvins

σ = Stefan-Boltzmann constant = 5.670373×10^{-8} watts/m^2 K^4

$$j^*{}_A = \sigma T_A{}^4 = 5.67 \times 10^{-8} \times 293.15^4 = 418.8\ \frac{watts}{m^2}$$

$$j^*{}_B = \sigma T_B{}^4 = 5.67 \times 10^{-8} \times 313.15^4 = 545.3\ \frac{watts}{m^2}$$

$$\frac{j^*{}_B}{j^*{}_A} = \frac{545.3}{418.8} = 1.302$$

Sphere B is emitting about 1.3 times as much energy as (or 30 % more than) sphere A.

Alternately, one could calculate the ratios of the temperatures (in kelvins!), then raise that ratio to the 4th power, to obtain the same result:

$$\left\{\frac{T_B}{T_A}\right\}^4 = \left\{\frac{313.15}{293.15}\right\}^4 = \{1.0682\}^4 = 1.302$$

Note: if students don't convert the temperatures from the Celsius scale to the Kelvin scale, they might mistakenly conclude that sphere B is emitting 16 times as much energy as sphere A; based on the false assumption that sphere B is twice as hot (40°/20°) as sphere A.

2. Suppose you had two black, iron spheres. Sphere A is emitting about 5 times more electromagnetic radiation than sphere B. Calculate the relative temperatures of the two spheres.

$$\frac{j^*{}_A}{j^*{}_B} = \left\{\frac{\sigma T_A}{\sigma T_B}\right\}^4 = \left\{\frac{T_A}{T_B}\right\}^4$$

$$\frac{T_A}{T_B} = \sqrt[4]{\frac{j^*{}_A}{j^*{}_B}} = \sqrt[4]{\frac{5}{1}} = \sqrt[4]{5} = 1.495$$

Sphere A is about 50% (1.5 times) warmer than sphere B.

Note, we cannot determine the **absolute** temperatures of the two spheres. Sphere A might have a temperature of 75 kelvins (-198° C or -325° F) compared to sphere B's temperature of 50 kelvins (-223° C or -370° F) … or sphere A might be at 300 kelvins (27° C or 80° F) while sphere B is at 200 kelvins (-73° C or -100° F)… or any number of other possibilities for which the temperature of sphere A is 50% higher (on the Kelvin scale!) than the temperature of sphere B.