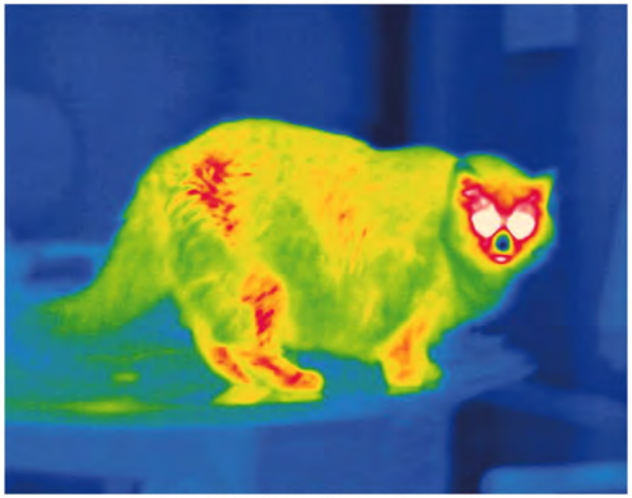
18-6 Heat Transfer Mechanisms

Thermal Radiation

Radiation is an energy transfer via the emission of electromagnetic energy. The rate P_{rad} at which an object emits energy via thermal radiation is

$$P_{\mathrm{rad}} = \sigma \varepsilon A T^4.$$



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Here σ (= 5.6704×10^{-8} W/m^2.K^4) is the Stefan– Boltzmann constant, ε is the emissivity of the object's surface, A is its surface area, and T is its surface temperature (in kelvins). The rate P_{abs} at which an object absorbs energy via thermal radiation from its environment, which is at the uniform temperature T_{env} (in kelvins), is

$$P_{\mathrm{abs}} = \sigma \varepsilon A T^4_{\mathrm{env}}.$$

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$P_{rad} = \sigma \varepsilon A T^4.$

$P_{abs} = \sigma \varepsilon A T_{env}^4.$

black body: ε=1 blackbody radiation $\sigma = 5.6704 \times 10^{-8}$ W/m^2.K^4

Example: the power per unit area from the sun reaching the earth is 1400W/m^2. **Assume ε=1 for sun and earth.**

(a) What is the temperature of the earth's surface?
(b) What is the temperature of the sun's surface?
(c) What is the temperature of the sun's center?

What other data do you need to answer these questions?

$P_{earth}=\sigma T_e^4$ =1400W/m^2 **==> T_e=396K** (a)

sun radius: 7x10^{8}m, distance earth-sun=1.5x10^{11}m

$P_{earth} x 4\pi d^2 = P_{sun} x 4\pi R_s^2$ ==> $\sigma T_e^4 x 4\pi d^2 = \sigma T_s^4 x 4\pi R_s^2$

==> $T_s = T_e^4 x (d/R_s)^{1/2}$ **==> T_s=5800K** (b)

(c) $T_{sun\ center}$=15,000,000K can't tell you why

18 Summary

Temperature and Thermometer

- SI base quantity related to our sense of hot and cold.
- It is measured using thermometer

Zeroth Law of Thermodynamics

- If bodies A and B are each in thermal equilibrium with a third body C (the thermometer), then A and B are in thermal equilibrium with each other.

The Kelvin Temperature Scale

- We define the temperature T as measured with a gas thermometer to be

$$T = (273.16\text{ K})\left(\lim_{\text{gas}\to 0} \frac{p}{p_3}\right).$$ **Eq. 18-6**

Celsius and Fahrenheit Scale

- The Celsius temperature scale is defined by

$$T_C = T - 273.15^\circ$$ **Eq. 18-7**

- The Fahrenheit temperature scale is defined by

$$T_F = \tfrac{9}{5}T_C + 32^\circ.$$ **Eq. 18-8**

Thermal Expansion

- Linear Expansion

$$\Delta L = L\alpha\,\Delta T,$$ **Eq. 18-9**

- Volume Expansion

$$\Delta V = V\beta\,\Delta T.$$ **Eq. 18-10**

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18 Summary

Heat Capacity and Specific Heat

- Heat Capacity:

$$Q = C(T_f - T_i).$$ **Eq. 18-13**

- Specific Heat

$$Q = cm(T_f - T_i),$$ **Eq. 18-14**

First Law of Thermodynamics

- The principle of conservation of energy for a thermodynamic process is expressed in:

$$\Delta E_{int} = E_{int,f} - E_{int,i} = Q - W$$ **Eq. 18-26**

$$dE_{int} = dQ - dW$$ **Eq. 18-27**

Application of First Law

adiabatic processes: $Q = 0, \quad \Delta E_{int} = -W$

constant-volume processes: $W = 0, \quad \Delta E_{int} = Q$

cyclical processes: $\Delta E_{int} = 0, \quad Q = W$

free expansions: $Q = W = \Delta E_{int} = 0$

Conduction, Convection, Radiation

- Conduction

$$P_{cond} = \frac{Q}{t} = kA\,\frac{T_H - T_C}{L}$$ **Eq. 18-32**

- Radiation:

$$P_{rad} = \sigma \varepsilon A T^4$$ **Eq. 18-39**

18.6.4. Which one of the following statements is the best explanation for the fact that metal pipes that carry water often burst during cold winter months?

a) Both the metal and the water expand, but the water expands to a greater extent.

b) Water contracts upon freezing while the metal expands at lower temperatures.

c) The metal contracts to a greater extent than the water.

d) The interior of the pipe contracts less than the outside of the pipe.

e) Water expands upon freezing while the metal contracts at lower temperatures.

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18.7.1. Why is water often used as a coolant in automobiles, other than the fact that it is abundant?

a) Water expands very little as it is heated.

b) The freezing temperature of water has a relatively large value.

c) The specific heat of water is relatively small and its temperature can be rapidly decreased.

d) The specific heat of water is relatively large and it can store a great deal of thermal energy.

e) Water does not easily change into a gas.

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18.8.1. A certain amount of heat Q is added to materials A, B, and C. The masses of these three materials are 0.04 kg, 0.01 kg, and 0.02 kg, respectively. The temperature of material A increases by 4.0 C° while the temperature of the other two materials increases by only 3.0 C°. Rank these three materials from the largest specific heat capacity to the smallest value.

a) A > B > C

b) C > B > A

c) B > A > C

d) B = C > A

e) A > B = C

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18.8.3. Which of the following substances would be the most effective in cooling 0.300 kg of water at 98 °C?

a) 0.100 kg of lead at 22 °C

b) 0.100 kg of water at 22 °C

c) 0.100 kg of glass at 22 °C

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18.8.6. Heat is added to a substance, but its temperature does not increase. Which one of the following statements provides the best explanation for this observation?

a) The substance has unusual thermal properties.

b) The substance must be cooler than its environment.

c) The substance must be a gas.

d) The substance must be an imperfect solid.

e) The substance undergoes a change of phase.

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18.10.1. An insulated container is filled with a mixture of water and ice at zero °C. An electric heating element inside the container is used to add 1680 J of heat to the system while a paddle does 450 J of work by stirring. What is the increase in the internal energy of the ice-water system?

a) 450 J

b) 1230 J

c) 1680 J

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e) zero J

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18.10.2. The internal energy of a system increases during some time interval. Which one of the following statements concerning this situation must be true?

a) The increase in internal energy indicates that work was done on the system.

b) The increase in internal energy indicates that heat was added to the system.

c) The increase in internal energy indicates that work was done by the system.

d) The increase in internal energy indicates that heat was removed from the system.

e) The information given is insufficient to indicate the reason for the increase.

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18.10.3. A gas is enclosed in a cylinder by a piston. The volume of the gas is then reduced to one half its original value by applying a force to the piston. Which one of the following statements concerning the internal energy of the gas is true?

a) The internal energy of the gas will decrease.

b) The internal energy of the gas will increase.

c) The internal energy of the gas will neither increase nor decrease.

d) The internal energy of the gas will equal the work done in moving the piston.

e) The internal energy of the gas may increase, decrease, or remain the same depending on the amount of heat that is gained or lost by the gas.

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