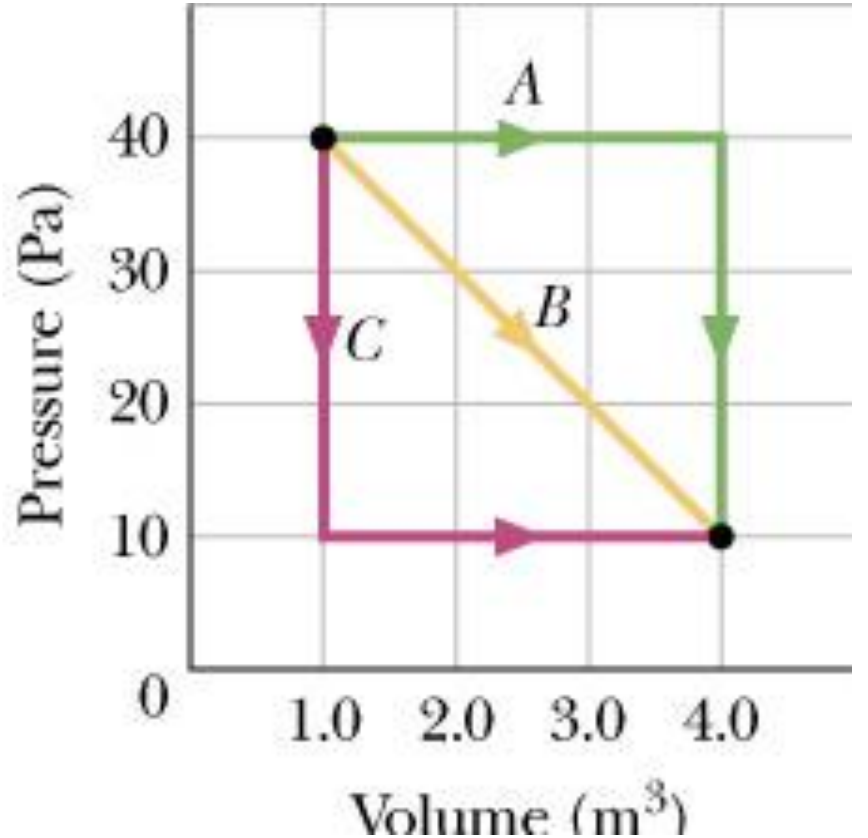
Homework:

43, 44, 46, 47, 48, 49, 50 (pages 502, 503)

43. A gas sample 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 (a) path A, (b) path B, and (c) path C?

$$W = \int p dV$$



(a)

$$W = p\Delta V + 0 = 40 \times 3 = 120(J)$$

(b)

$$W = \frac{1}{2}(10 + 40)3 = 75(J)$$

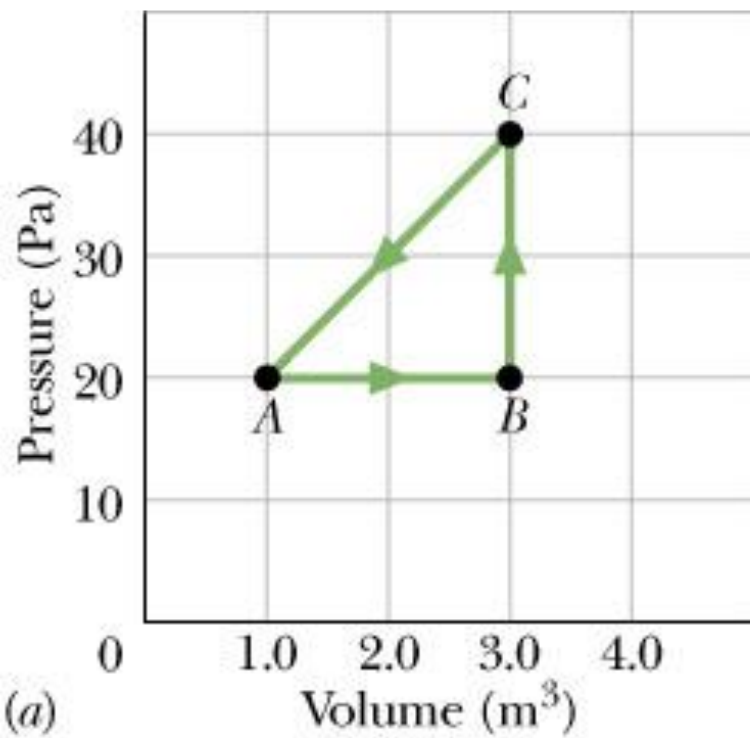
or you can use

$$W = \int p dV = \int_1^4 (50 - 10V)dV = (50V - 5V^2)|_1^4 = 75(J)$$

(c)

$$W = 0 + p\Delta V = 10 \times 3 = 30(J)$$

44. A thermodynamic system is taken from state A to state B to state C, and then back to A, as shown in the p-V diagram of Fig.a. (a)-(g) Complete the table in Fig.b by inserting a plus sign, a minus sign, or a zero in each indicated cell. (h) What is the net work done by the system as it moves once through the cycle ABCA?



(a)

	Q	W	ΔE_{int}
$A \longrightarrow B$	(a) +	(b) +	+
$B \longrightarrow C$	+	(c) 0	+ (d)
$C \longrightarrow A$	− (e)	− (f)	− (g)

(b)

$$\Delta E_{int} = Q - W$$

$$W = -\frac{1}{2} AB \times BC = -\frac{1}{2} 2 \times 20 = -20(J)$$

46. Suppose 200 J of work is done on a system and 80.0 cal is extracted from the system as heat. In the sense of the first law of thermodynamics, what are the values (including algebraic signs) of (a) W, (b) Q, and (c) ΔE_{int}?

(a)

$$W_{on} = 200\,J$$

Work done on the gas = - work done by the gas

W_{on} = - W

$$W = -W_{on} = -200\,(J)$$

(b) the gas released energy as heat, so Q<0:

$$Q = -80\,cal = -80 \times 4.19 = -335.2(J)$$

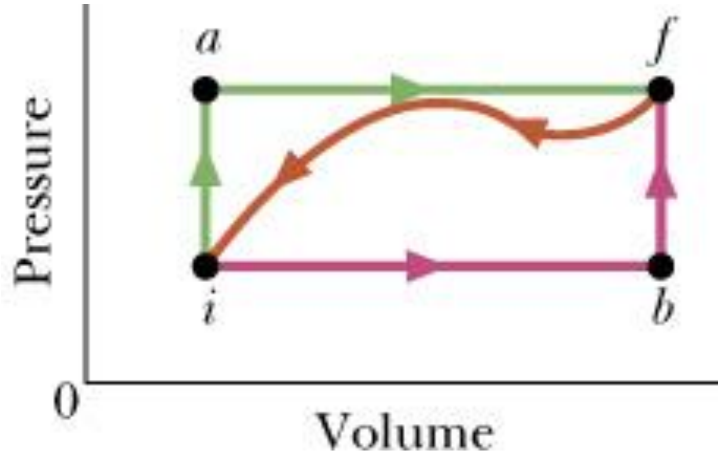
(c) the first law of thermodynamics:

$$\Delta E_{int} = Q - W$$

$$\Delta E_{int} = -335.2 - (-200) = -135.2(J)$$

47. When a system is taken from state i to state f along path iaf in the figure below, Q = 50 cal and W = 20 cal. Along path ibf, Q = 36 cal. (a) What is W along path ibf? (b) If W = -13 cal for the return path fi, what is Q for this path? (c) If $E_{int,i}$ = 10 cal, what is $E_{int,f}$? If $E_{int,b}$ = 22 cal, what is Q for (d) path ib and (e) path bf?

$$\Delta E_{int} = Q - W$$



(a) For path iaf:

$$\Delta E_{int,iaf} = E_{int,f} - E_{int,i} = Q_{iaf} - W_{iaf}$$

For path ibf:

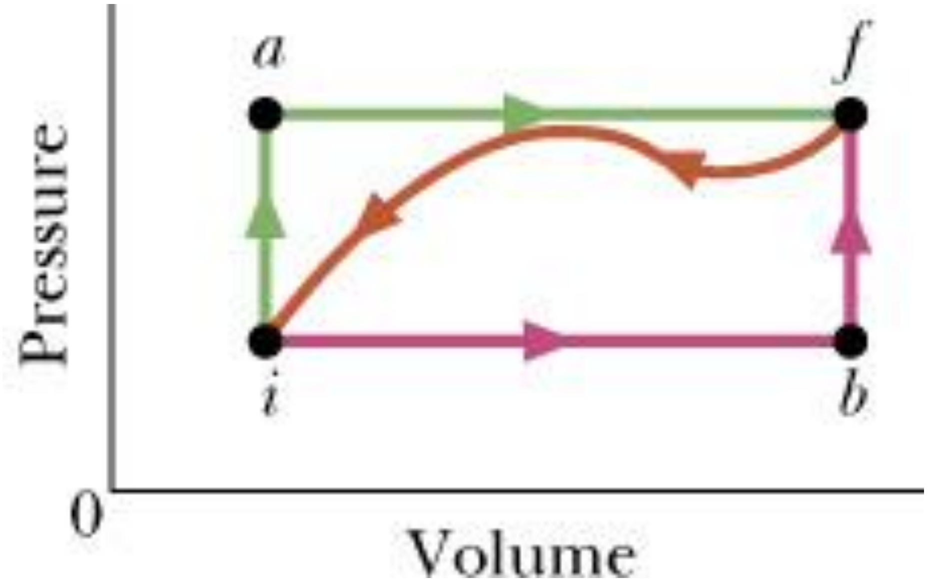
$$\Delta E_{int,ibf} = E_{int,f} - E_{int,i} = Q_{ibf} - W_{ibf} = \Delta E_{int,iaf}$$

$$\Rightarrow W_{ibf} = Q_{ibf} - (Q_{iaf} - W_{iaf}) = 36 - (50 - 20) = 6(\text{cal})$$

(b) For path fi: $\Delta E_{int,fi} = E_{int,i} - E_{int,f} = -\Delta E_{int,if} = -30(\text{cal})$

$$Q_{fi} = \Delta E_{int,fi} + W = -30 - 13 = -43(\text{cal})$$

(c) For path fi: $E_{int,f} = E_{int,i} - \Delta E_{int,fi} = 10 - (-30) = 40(\text{cal})$



(d) For path ibf:

$$W_{ibf} = W_{ib} = 6\,(\text{cal})\ \text{as}\ W_{bf} = 0\ (\text{constant volume})$$

$$\Delta E_{int,ib} = E_{int,b} - E_{int,i} = 22 - 10 = 12(\text{cal})$$

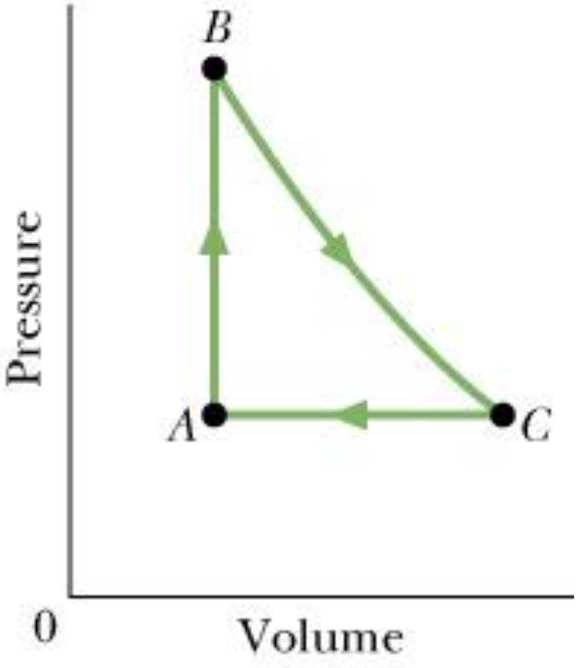
$$Q_{ib} = \Delta E_{int,ib} + W_{ib} = 12 + 6 = 18(\text{cal})$$

(e) For path ibf:

$$Q_{bf} = Q_{ibf} - Q_{ib} = 36 - 18 = 18(\text{cal})$$

48. 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 25.0 J, no energy is transferred as heat during process *BC*, and the net work done during the cycle is 15.0 J.

$$\Delta E_{int} = Q - W$$



For the ABCA closed cycle:

$$\Delta E_{int} = 0$$

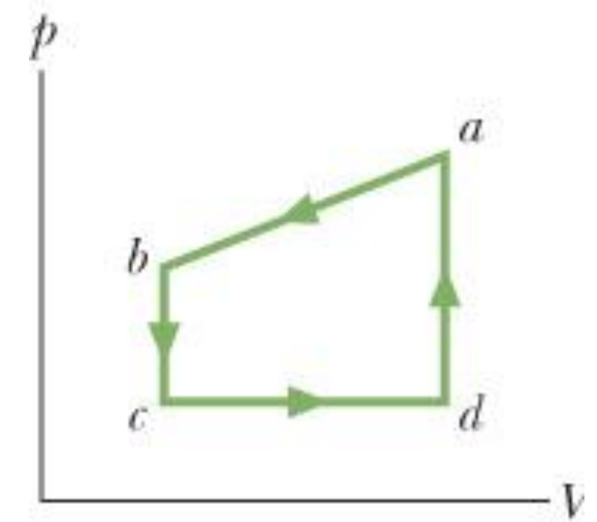
$$Q_{AB} + Q_{BC} + Q_{CA} = W$$

$$Q_{CA} = W - Q_{AB} - Q_{BC}$$

$$Q_{CA} = 15 - 25 - 0 = -10 \text{ (J)}$$

49. The figure below displays a closed cycle for a gas (the figure is not drawn to scale). The change in the internal energy of the gas as it moves from *a* to *c* along the path *abc* is -200 J. As it moves from *c* to *d*, 180 J must be transferred to it as heat. An additional transfer of 80 J as heat is needed as it moves from *d* to *a*. How much work is done by the gas as it moves from *c* to *d*?

$$\Delta E_{int} = Q - W$$



For a closed cycle:

$$\Delta E_{int} = 0$$

$$\Delta E_{abc} + \Delta E_{cd} + \Delta E_{da} = 0$$

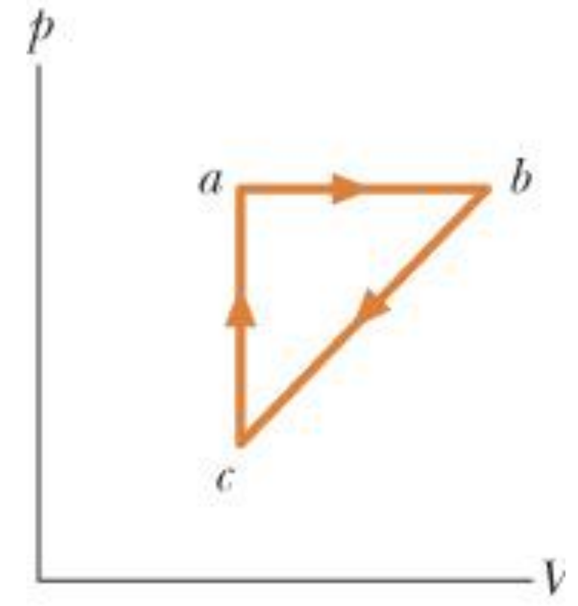
$$\Delta E_{abc} = -200\,(J)$$

For process da: $\Delta E_{da} = Q - W = 80 - 0 = 80\,(J)$

$$\Delta E_{cd} = 200 - 80 = 120\,(J)$$

$$\Rightarrow W_{cd} = Q_{cd} - \Delta E_{cd} = 180 - 120 = 60\,(J)$$

50. A sample of gas is taken through cycle *abca* shown in the p-V diagram (see figure). The net work done is +1.5 J. Along path *ab*, the change in the internal energy is +3.0 J and the magnitude of the work done is 5.0 J. Along path *ca*, the energy transferred to the gas as heat is 2.5 J. How much energy is transferred as heat along (a) path *ab* and (b) path *bc*?



$$\Delta E_{int} = Q - W$$

(a) This process a→b is an expansion ($V_b > V_a$):

$$W > 0 \text{ and } W = 5\text{ J}$$

$$Q_{ab} = \Delta E_{int} + W = 3 + 5 = 8\,(\text{J})$$

(b) We consider a closed cycle abca:

$$\Delta E_{int} = Q - W = 0$$

$$Q_{ab} + Q_{bc} + Q_{ca} = W_{net}$$

$$Q_{bc} = W_{net} - Q_{ab} - Q_{ca} = 1.5 - 8 - 2.5 = -9.0\,(\text{J})$$

Chapter 2 Heat, Temperature and the First Law of Thermodynamics

2.1. Temperature and the Zeroth Law of Thermodynamics

2.2. Thermal Expansion

2.3. Heat and the Absorption of Heat by Solids and Liquids

2.4. Work and Heat in Thermodynamic Processes

2.5. The First Law of Thermodynamics and Some Special Cases

2.6. Heat Transfer Mechanisms

2.6. Heat Transfer Mechanisms

There are three types of transfer of energy as heat between a system and its environment: conduction, convection, and radiation.

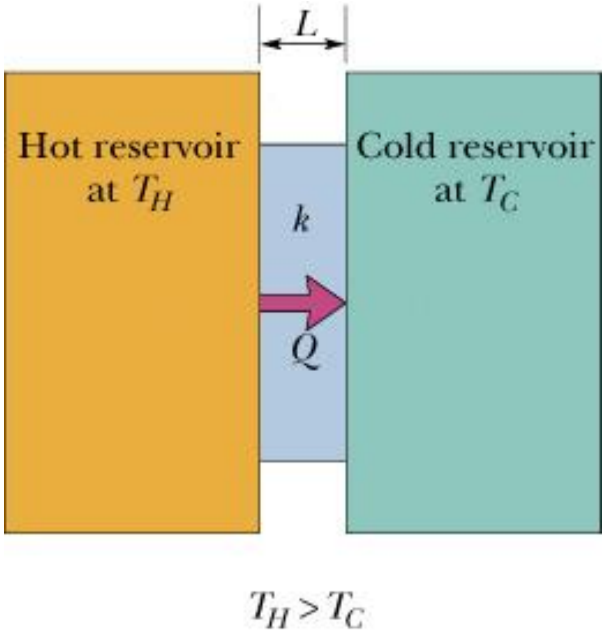
2.6.1. Conduction:

Example: Leaving the end of a metal poker in a fire ➔ its handle gets hot because energy is transferred from the fire to the handle by conduction.

Physical mechanism: Due to the high temperature of the poker's environment, the vibration amplitudes of the atoms and electrons of the metal are relatively large, and thus the associated energy are passed along the poker, from atom to atom during collisions between adjacent atoms.

•We consider a slab of face area A, thickness L, in thermal contact with a hot reservoir T_H and a cold reservoir T_C:

- Let Q be the energy transferred as heat through the slab in time t.
- Based on experiment, the conduction rate, which is the amount of energy transferred per unit time, is calculated by:



$$P_{cond} = \frac{Q}{t} = kA\frac{T_H - T_C}{L}$$ (Unit: W = J/s)

k is called the thermal conductivity; good thermal conductors (or poor thermal insulator) have high k-values.

Material	Thermal conductivity ($Wm^{-1}K^{-1}$)
Diamond	1000
Metals	
Silver	428
Copper	401
Gold	314
Aluminum	235
Brass	109
Iron	67
Steel	50
Lead	35
Stainless steel	14

Material	Thermal conductivity ($Wm^{-1}K^{-1}$)
Gases	
Hydrogen	0.18
Helium	0.15
Air (dry)	0.026
Building Materials	
Window glass	1.0
White pine	0.11
Fiberglass	0.048
Rock wool	0.043
Polyurethane form	0.024

Thermal Resistance to Conduction:

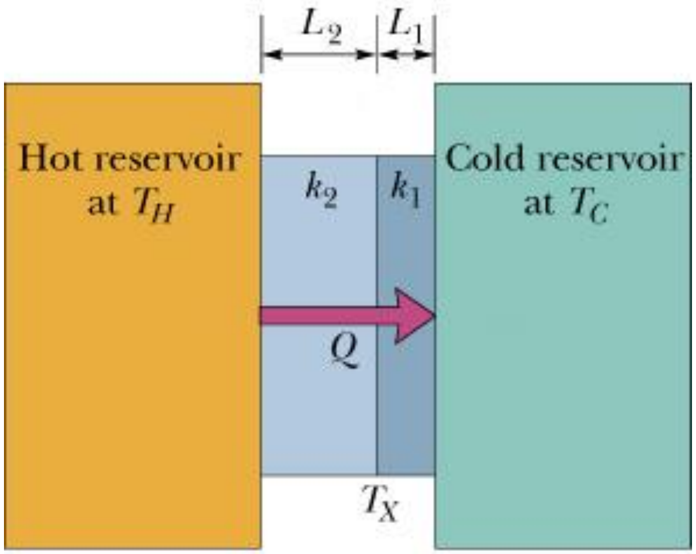
A measure of a body's ability to prevent heat from flowing through it.

$$R = \frac{L}{k}; L: \text{the thickness of the slab}$$

Good thermal insulators (poor thermal conductors) have high R-values.

Conduction Through a Composite Slab:

A composite slab consisting of two materials having thicknesses L1 and L2, and thermal conductivities k1 and k2.



If the transfer is a steady-state process that is *the temperature everywhere in the slab and the rate of energy transfer do not change with time.*

$$P_{cond} = \frac{k_2 A(T_H - T_X)}{L_2} = \frac{k_1 A(T_X - T_C)}{L_1}$$

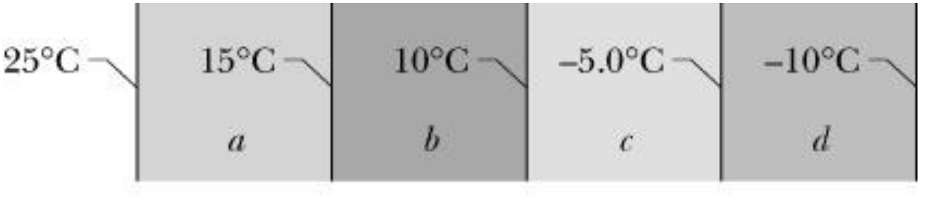
$$P_{cond} = \frac{A(T_H - T_C)}{L_1/k_1 + L_2/k_2}$$

If the slab consists of n materials:

$$P_{cond} = \frac{A(T_H - T_C)}{\sum_{i=1}^{n} (L_i/k_i)}$$

Checkpoint 7: The figure shows the face and interface temperature of a composite slab consisting of four materials, of identical thickness, through which the heat transfer is steady. Rank the materials according to their thermal conductivities, greatest first.

$$P_{cond} = k_x A \frac{T_H - T_C}{L_x}$$



The heat transfer is steady, therefore $P_a=P_b=P_c=P_d$.

$$k_a(T_1 - T_2) = k_b(T_2 - T_3) = k_c(T_3 - T_4) = k_d(T_4 - T_5)$$

$$k_b k_d k_a k_c$$

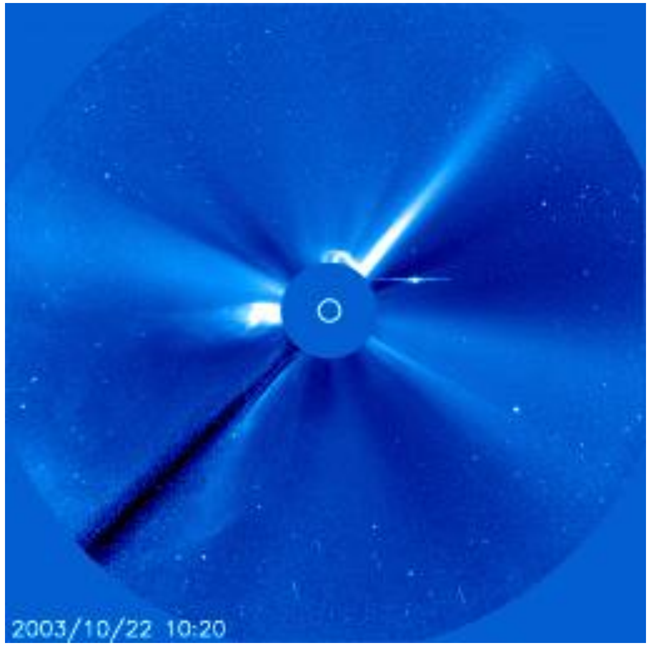
2.6.2. Convection:

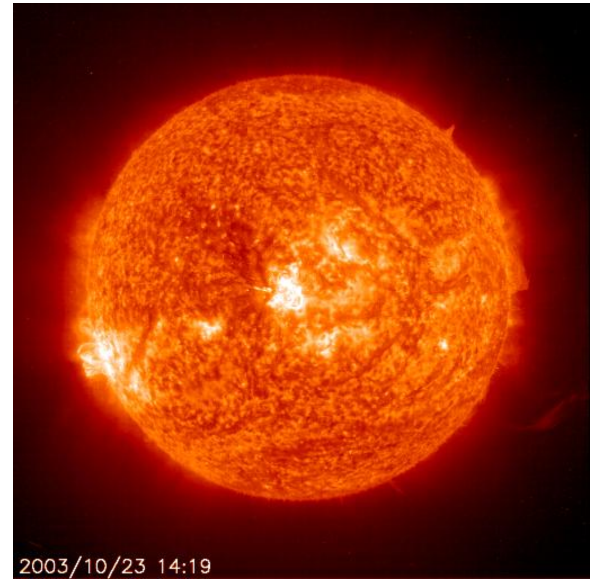
Energy is transferred through fluid motion (gases, liquids).

Physical mechanism: When a fluid comes in contact with an object whose temperature is higher than that of the fluid. The part of the fluid in contact with the hot object has a temperature higher than that of the surrounding cooler fluid, hence that fluid becomes less dense; buoyant forces cause it rise. The cooler fluid flows to take the place of the rising warmer fluid, producing fluid motion.

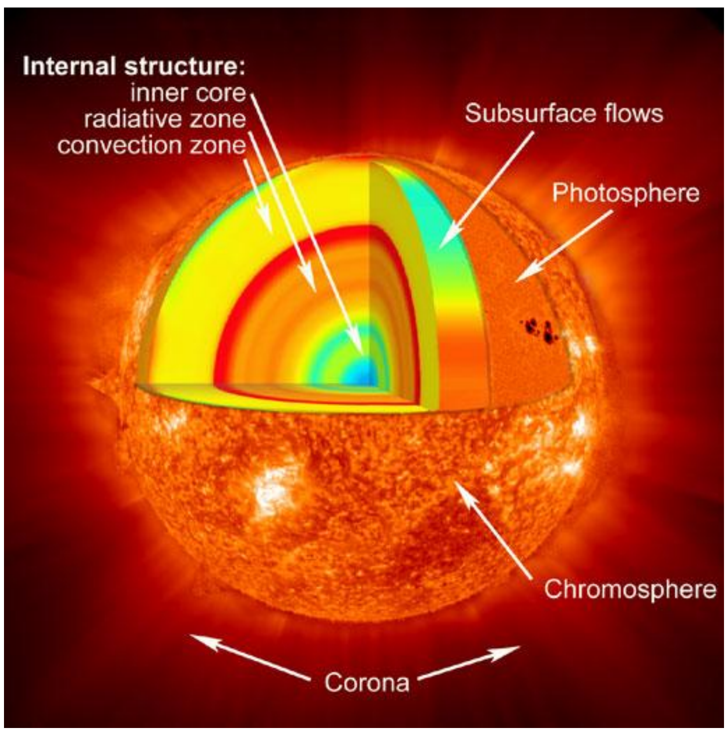
Examples: convection in the Earth's atmosphere; in the oceans, in the Sun.

Hurricane Felix (NASA)

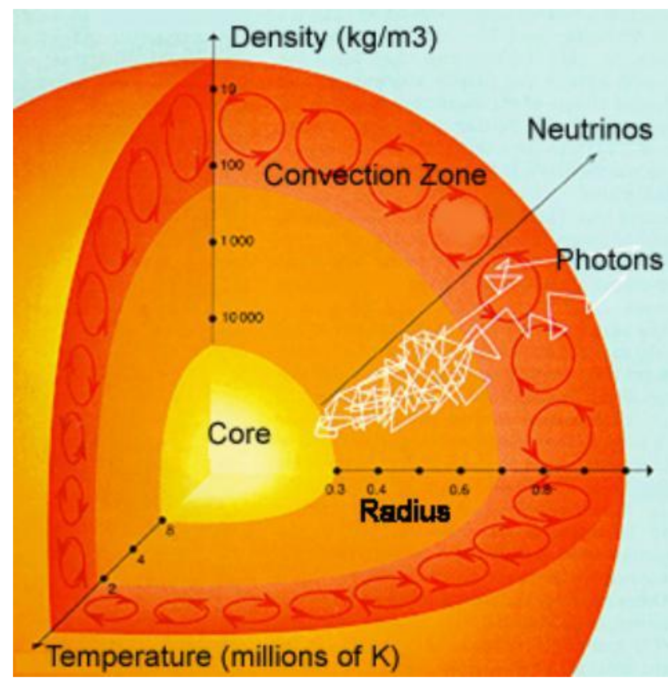




SOHO/NASA



NASA



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2.6.3. Radiation:

Thermal energy is transferred via electromagnetic waves.

Physical mechanism: Thermal radiation is generated when heat from the movement of charged particles within atoms and molecules is converted to electromagnetic radiation.

Properties:

+ Every object whose temperature above 0 K emits thermal radiation via electromagnetic waves.

+ No medium is required for heat transfer via radiation.

+ The rate of emitting energy of an object is given by:

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

$\sigma = 5.6703 \times 10^{-8}\ \mathrm{W\,m^{-2}\,K^{-4}}$: the Stefan - Boltzmann constant

ε is the emissivity of the object's surface (values from 0 to 1)

$\varepsilon = 1$: an idealized blackbody radiator will absorp all the radiated energy it intercepts

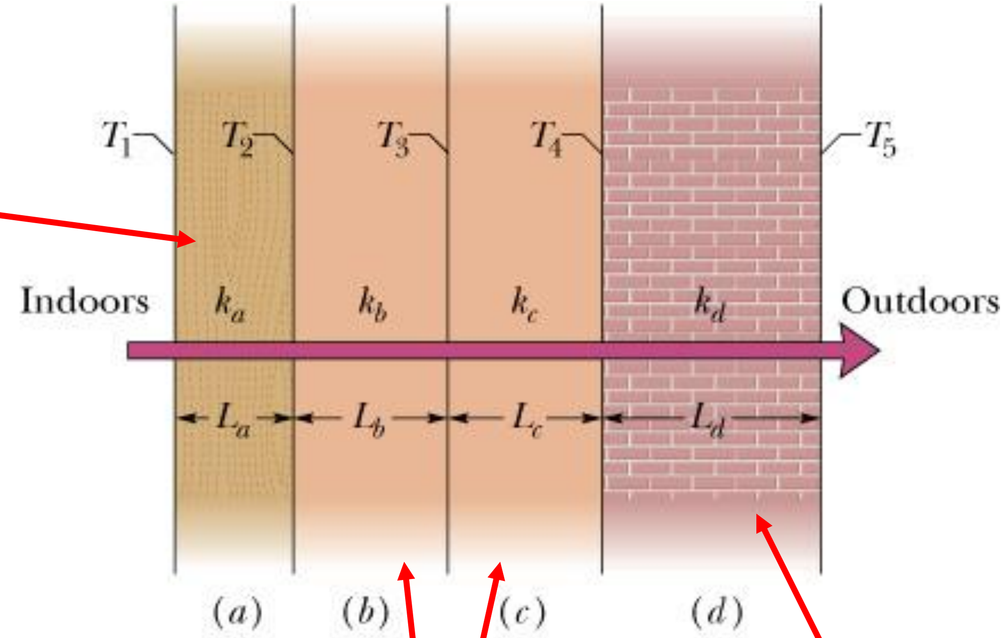
A is the object's surface area

T is the object's surface temperature

Sample Problem (p. 497)

L_d = 2 L_a (thickness)
k_d = 5 k_a (conductivity)
The heat transfer is steady
$T_1=25^0C$; $T_2=20^0C$; $T_5=-10^0C$
T_4?

White pine



Unknown material

brick

$$k_a A \frac{T_1 - T_2}{L_a} = k_d A \frac{T_4 - T_5}{L_d}$$

$$T_4 = \frac{k_a L_d}{k_d L_a}(T_1 - T_2) + T_5$$

$$L_d = 2L_a \text{ and } k_d = 5k_a \Rightarrow T_4 = \frac{k_a (2L_a)}{(5k_a)L_a}(25 - 20) - 10 = \text{-}8(^0\text{C})$$

Homework: 51, 54, 59, 60 (pages 503, 504)