Phys101 Lectures 33, 34

Heat Transfer

Key points:

- **Heat as Energy Transfer**
- **Specific Heat**
- **Heat Transfer: Conduction, Convection, Radiation.**

Ref: 14-1,2,3,4,6,7,8.

Heat as Energy Transfer

We often speak of **heat** as though it were a **material** that flows from one object to another; it is not. Rather, it is a form of **energy**.

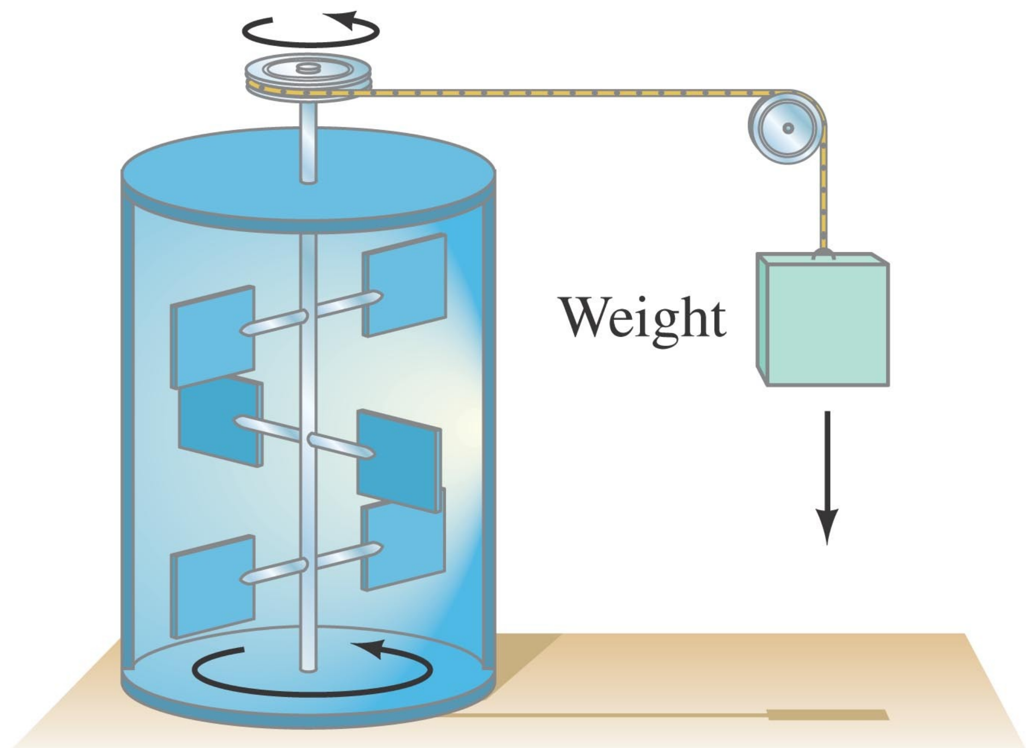
Unit of heat: **calorie** (cal)

1 **cal** is the amount of **heat** necessary to raise the **temperature** of 1 g of water by **1 Celsius degree**.

Don’t be fooled—the calories on our food labels are really **kilocalories** (kcal or Calories), the heat necessary to raise 1 kg of water by 1 Celsius degree.

Heat as Energy Transfer

If **heat** is a form of **energy**, it ought to be possible to equate it to other forms. The experiment below found the **mechanical equivalent of heat** by using the falling weight to heat the water:



4.186 J = 1 cal

4.186 kJ = 1 kcal

Heat as Energy Transfer

Definition of heat:

Heat is energy transferred from one object to another because of a difference in temperature.

- **From chemistry we know that the temperature of a gas is a measure of the kinetic energy of its molecules.**

Specific Heat

TABLE 14–1 Specific Heats
(at 1 atm constant pressure and 20°C unless otherwise stated)

Substance	Specific Heat, c kcal/kg · C° (= cal/g · C°)	J/kg · C°
Aluminum	0.22	900
Alcohol (ethyl)	0.58	2400
Copper	0.093	390
Glass	0.20	840
Iron or steel	0.11	450
Lead	0.031	130
Marble	0.21	860
Mercury	0.033	140
Silver	0.056	230
Wood	0.4	1700
Water		
Ice (−5°C)	0.50	2100
Liquid (15°C)	1.00	4186
Steam (110°C)	0.48	2010
Human body (average)	0.83	3470
Protein	0.4	1700

The amount of heat required to change the temperature of a material is proportional to the **mass** and to the **temperature change**:

$$Q = mc\,\Delta T.$$

The **specific heat**, c, is characteristic of the material. Some values are listed at left.

Example (14-2):

(a) How much heat input is needed to raise the temperature of an empty 20-kg vat made of iron from 10°C to 90°C?

(b) What if the vat is filled with 20 kg of water?

Calorimetry—Solving Problems

Closed system: **no mass** enters or leaves, but energy may be exchanged

Open system: mass may transfer as well

Isolated system: closed system in which **no energy** in any form is transferred

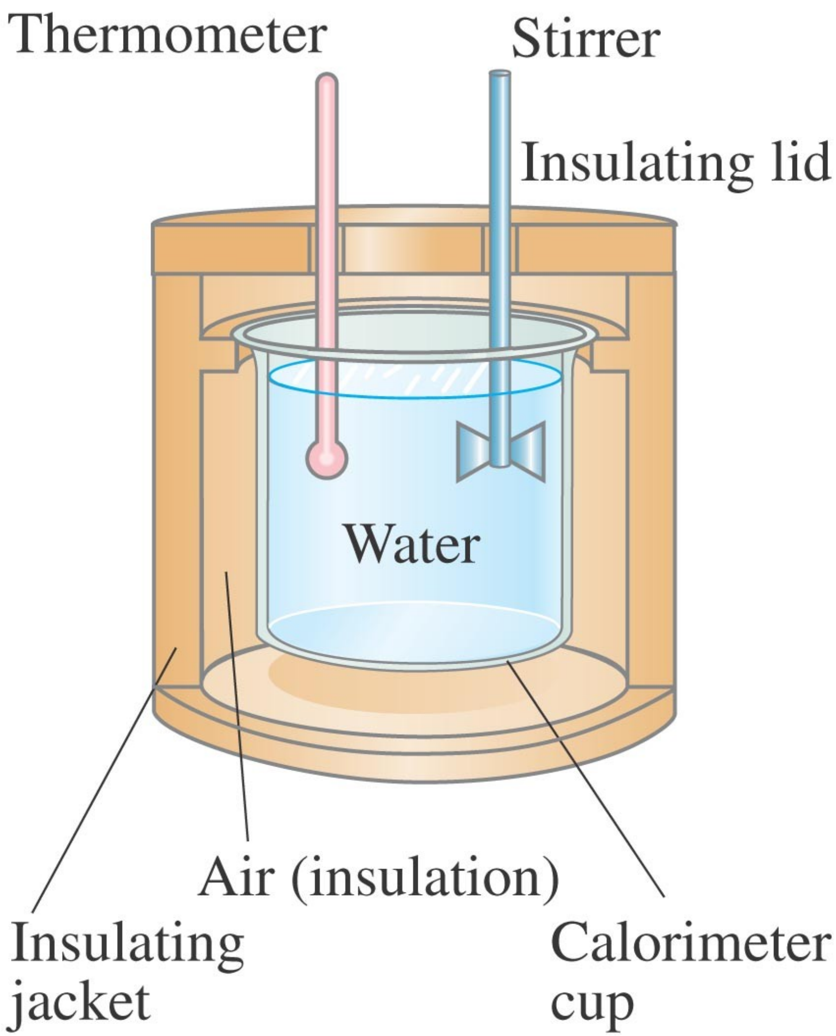
For an isolated system,

energy out of one part = energy into another part

Example 14-4: The cup cools the tea.

If 200 cm^3 of tea at 95°C is poured into a 150-g glass cup initially at 25°C, what will be the common final temperature T of the tea and cup when equilibrium is reached, assuming no heat flows to the surroundings?

Calorimetry—Solving Problems



The instrument to the left is a **calorimeter**, which makes **quantitative** measurements of heat exchange. A sample is heated to a well-measured high temperature and plunged into the water, and the **equilibrium** temperature is measured. This gives the **specific heat** of the sample.

Example: Unknown specific heat determined by calorimetry.

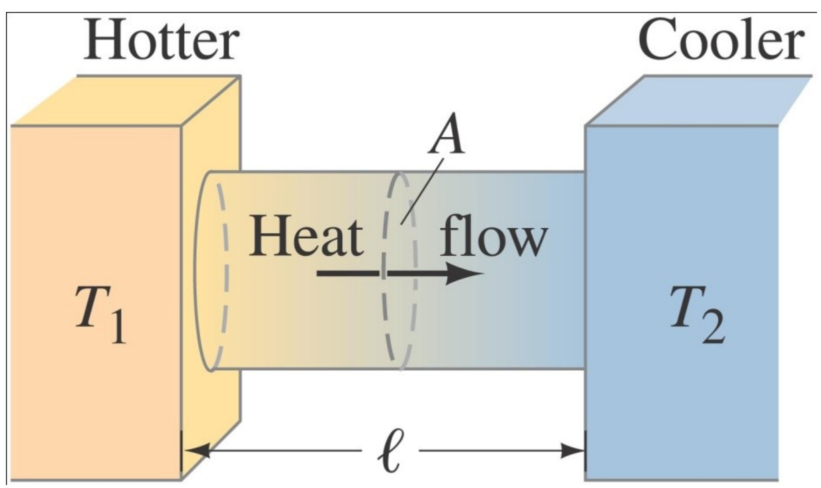
An engineer wishes to determine the specific heat of a new metal alloy. A 0.150-kg sample of the alloy is heated to 540°C. It is then quickly placed in 0.400 kg of water at 10.0°C, which is contained in a 0.200-kg aluminum calorimeter cup. The final temperature of the system is 30.5°C. Calculate the specific heat of the alloy.

Heat Transfer: Conduction, Convection, Radiation

Heat **conduction** can be visualized as occurring through molecular **collisions**.

The **heat flow** per unit time is given by:

$$\frac{\Delta Q}{\Delta t} = kA\frac{T_1 - T_2}{\ell}.$$



Heat Transfer: Conduction, Convection, Radiation

TABLE 14–4
Thermal Conductivities

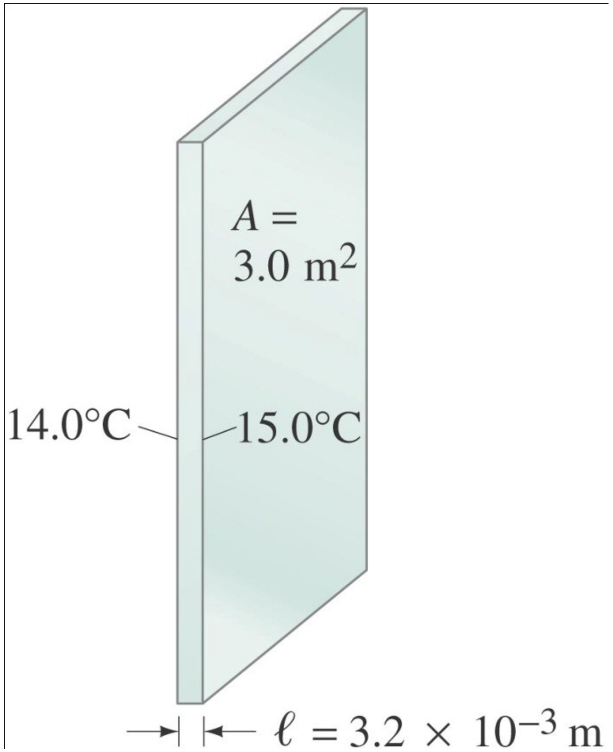
Substance	Thermal Conductivity, k: $\frac{\text{kcal}}{(\text{s}\cdot\text{m}\cdot\text{C}^\circ)}$	Thermal Conductivity, k: $\frac{\text{J}}{(\text{s}\cdot\text{m}\cdot\text{C}^\circ)}$
Silver	10×10^{-2}	420
Copper	9.2×10^{-2}	380
Aluminum	5.0×10^{-2}	200
Steel	1.1×10^{-2}	40
Ice	5×10^{-4}	2
Glass	2.0×10^{-4}	0.84
Brick	2.0×10^{-4}	0.84
Concrete	2.0×10^{-4}	0.84
Water	1.4×10^{-4}	0.56
Human tissue	0.5×10^{-4}	0.2
Wood	0.3×10^{-4}	0.1
Fiberglass	0.12×10^{-4}	0.048
Cork	0.1×10^{-4}	0.042
Wool	0.1×10^{-4}	0.040
Goose down	0.06×10^{-4}	0.025
Polyurethane	0.06×10^{-4}	0.024
Air	0.055×10^{-4}	0.023

The constant k is called the **thermal conductivity**.

Materials with large k are called **conductors**; those with small k are called **insulators**.

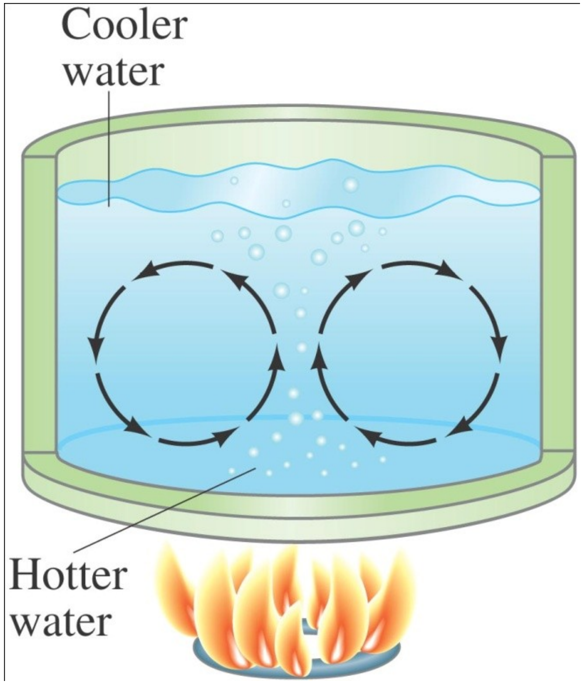
Example: Heat loss through windows.

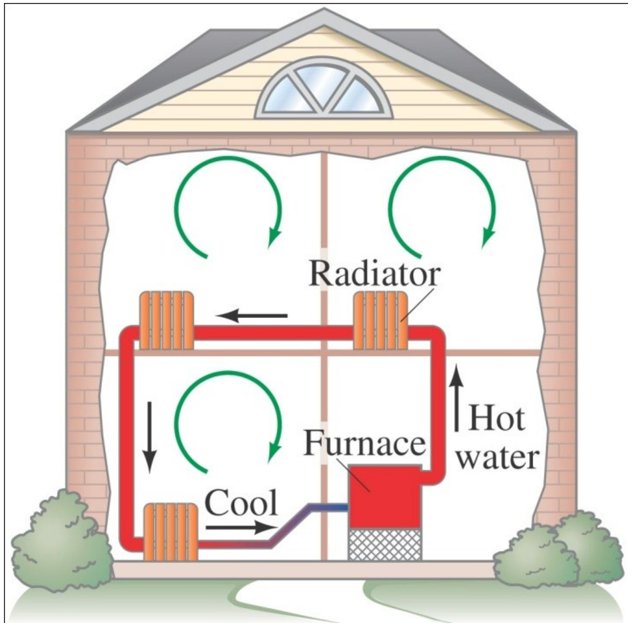
A major source of heat loss from a house is through the windows. Calculate the rate of heat flow through a glass window 2.0 m x 1.5 m in area and 3.2 mm thick, if the temperatures at the inner and outer surfaces are 15.0°C and 14.0°C, respectively.



Heat Transfer:
Conduction, Convection, Radiation

Convection occurs when heat flows by the mass **movement** of molecules from one place to another. It may be **natural** or **forced**; both these examples are natural convection.





Heat Transfer: Conduction, Convection, Radiation

Radiation is the form of energy transfer we receive from the Sun; if you stand close to a fire, most of the heat you feel is radiated as well.

The **energy** radiated has been found to be proportional to the **fourth** power of the temperature:

$$\frac{\Delta Q}{\Delta t} = \epsilon \sigma A T^4.$$

Heat Transfer: Conduction, Convection, Radiation

The constant σ is called the **Stefan-Boltzmann constant:**

$$\sigma = 5.67 \times 10^{-8}\, \mathrm{W/m^2 \cdot K^4}.$$

The **emissivity** ε is a number between 0 and 1 characterizing the surface; black objects have an emissivity near 1, while shiny ones have an emissivity near 0. It is the same for absorption; a good emitter is also a good absorber.

Example: Cooling by radiation.

An athlete is sitting unclothed in a locker room whose dark walls are at a temperature of 15°C. Estimate his rate of heat loss by radiation, assuming a skin temperature of 34°C and $\varepsilon = 0.70$. Take the surface area of the body not in contact with the chair to be 1.5 m^2.